AUTOMOTIVE ELECTRICITY

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AUTOMOTIVE ELECTRICITY

A Text and Reference Work on the Construction, Operation, Characteristics and Maintenance of Automotive Ignition, Starting, Lighting and Storage Battery Equipment

BY

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PREFACE

The purpose of "Automotive Electricity" is to provide the necessary text material to meet the needs of the student who desires to specialize in automotive electrical and battery service work. It is the outgrowth of the instruction conducted by the author during the past six years in the training of automotive electricians and battery men at the School of Automotive Electricity, Inc., as well as the period during the World War when he was in charge of the automotive electrical training for auto mechanics at the U. S. Army School conducted at the University of Wisconsin. The subject matter has been especially prepared and arranged for home study purposes.

This treatise is not intended as an encyclopedia, although it does contain information on practically all makes and types of automotive electrical and battery systems. It was prepared expressly as a text to treat in detail the principles, construction, operation and characteristics of the many makes and types of automotive electrical and battery equipment, including their troubles and remedies. These facts make the work particularly suited as a reference for automotive service stations and their employees. The information concerning the ignition, starting and lighting systems given herein is not restricted solely to automobiles, but applies also to tractors, trucks, motorcycles, motorboats, aircraft and stationary engines, thus enabling the repairman to service every make and type of electrical system that may come to him in garage or electrical service station work.

In the preparation of the material, the author has received much valuable assistance from the various automotive and electrical manufacturers in the way of technical information and illustrative material. Since it is impossible to acknowledge herein each contributor individually, the author wishes to thank them collectively for their generous cooperation and assistance.

Special acknowledgement is due Professor Ben G. Elliott, M. E., of the University of Wisconsin, for his valuable cooperation

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MILWAUKEE, WISCONSIN,
March, 1925.

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AUTOMOTIVE ELECTRICITY

SECTION I

FUNDAMENTALS OF ELECTRICITY

1. Electricity as Applied to the Automobile.—Probably no other factor has played a more important part in making possible the modern automobile with its highly perfected four-, six-, eight-, or twelve-cylinder engine than has electricity in its many applications. In addition to igniting the fuel charges within the engine cylinders, it is also depended upon to crank the engine in starting, to provide proper illumination of the road for night driving, to operate the horn and other signal devices, and, in many cases, to operate cigar lighters, hand warmers, carburetor-heating devices, electric gear shifts, etc. In fact, it may be said that the perfection of the modern automotive vehicle engine, whether it be for an automobile, truck, tractor, motor cycle, motor boat, or airplane, has been brought about largely by the development of its electrical equipment.

Since the successful operation of the automobile depends so largely on its electrical equipment, it is, therefore, essential that this equipment be operated properly and be kept in the best of adjustment and repair. Moreover, in order that electrical adjustments and repairs may be made intelligently, quickly, and accurately, the repairman must have a clear understanding of the fundamental electrical and electromagnetic principles involved.

2. Forms of Electricity.—The exact nature of electricity is not known, but its effects, the laws governing its action, and the methods of controlling and using it in doing various kinds of work are well understood. Electricity may be divided into three classifications according to the nature of its effects: namely, *static*, *dynamic*, and *high-frequency* or radio waves.

Static electricity is that form of electricity produced through friction between certain materials. Glass and silk, for example, when rubbed together produce static electricity. The electricity thus produced remains normally at rest or in the form of stationary charges, but will readily dissipate itself when allowed to discharge to some other body or to the ground. Another common example of static electricity may be illustrated by bringing a finger close to a rapidly moving leather belt which is used for driving machinery. A momentary spark of considerable intensity will be obtained from the belt to the finger. The static charge of electricity in this instance is produced by the friction between the belt and the pulleys over which it runs. Static electricity plays a comparatively small part in the operation of the automobile.

Dynamic or *current* electricity is electricity in motion and capable of doing work. This is the form of electricity generated by chemical cells and generators. It is this form of electricity that is used almost exclusively in automotive electrical equipment, for example, the magneto, generator, starting motor, etc.

A *high-frequency current*, or electromagnetic "ether" disturbance, commonly known as a *radio wave*, is the form of electrical energy that may be vibrated. Practical applications of this form are made use of in radio work, that is, in wireless telephony and wireless telegraphy, and to some extent for medical purposes. Up to the present time very little use has been made of it in automotive electrical equipment.

3. Effects of Electric Current.—Experiments show that an electric current in flowing through certain circuits produces various physical, chemical, and magnetic changes or effects. These effects include: (1) heat, (2) light, (3) chemical, (4) magnetic, and (5) physiological effects. All these effects may be obtained in a single circuit, as shown in Fig. 1.

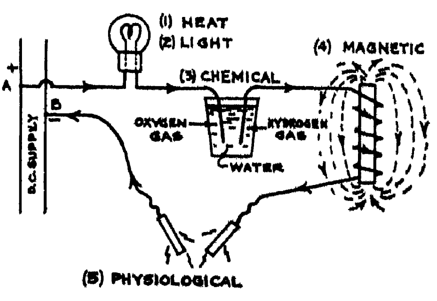


FIG. 1.—Effects of electric current.

Heat and Light.—Heat is developed to a greater or less degree in any conductor through which electricity flows, thereby causing the temperature to rise. If the current flowing is small, and the carrying capacity of the conductor is fairly high, the heat produced may be so small that a change in temperature is not noticeable. If the current flow, however, is increased sufficiently, the same conductor may glow with a red or a white heat on account of its high temperature, thus giving off light. As a matter of fact, incandescent lamps produce light because their filaments are heated to a white heat by the passage of an electric current.

Other practical applications of the heating effect of electric current are illustrated in the electric flatiron and toaster, and, on the automobile, in the ignition resistance units, carburetor-heating devices, cigar lighters, and electric hand warmers. Fuses used in lighting and generator circuits also operate (burn out) because the temperature of the fuse wire reaches the melting point of the wire, thereby opening the circuit and protecting it against possible damage. In all cases, the heat produced in the conductor represents a loss of electrical energy. The amount of heat developed depends upon the amount of current flowing and the resistance of the conductor.

Chemical Effect.—The chemical effect of an electric current may be readily seen by connecting test leads to the two connecting terminals of a storage battery and submerging the free ends in a glass of water in which a little common table salt has been dissolved. The passage of the current through the water will cause the formation of gas in the liquid because the water (H_2O) is broken up into its two component gases, hydrogen (H) and oxygen (O). The hydrogen gas accumulates in fine bubbles around the negative electrode, while the oxygen goes to the positive electrode. Since there are two parts of hydrogen produced to one of oxygen, and since the oxygen combines readily with the metal of the positive wire (especially if copper wire is used), the gassing will appear to take place chiefly around the negative electrode This fact provides an easy method of distinguishing between the positive and the negative polarity of live wires. The test may also be used to determine whether the current supply is direct or alternating, since in the case of alternating current the same amount of gassing will occur around both electrodes.

Magnetic Effect—The magnetic effect of an electric current may be readily demonstrated by holding a pocket magnetic compass needle near a wire that is carrying a direct current; for example, one of the headlight wires on an automobile. When the switch is turned on, the current in passing through the wire from the battery to the lamp will produce a magnetic effect or *field* around the wire of sufficient strength to cause the magnetic needle to turn crosswise of the wire.

The magnetic effect may also be demonstrated by sending a current from a battery through a coil of insulated wire wound on an iron bar and noting the attraction which the iron bar has for other pieces of iron. The iron bar is said to contain *magnetism*, the strength and direction of which is in direct relation to the amount and direction of current flowing.

Physiological Effect.—The physiological effect of electric current is witnessed in the effect it has on plant and animal cell life. It is the sensation or the reaction of the nerves and muscles that is actually felt when the hand or other parts of the body come into contact with a high-voltage conductor, such as a spark-plug wire or terminal. This physiological effect has no commercial value on the automobile, but it has been utilized in the treatment of certain ailments since the year 1880. It is wrong to say that one feels electricity, since electricity is not a material substance and is without length, breadth, thickness, and weight. In reality, it is merely the effects of electricity which are felt.

4. Methods of Generating Electric Current.—Electric current may be generated by reversing the heating, chemical, and magnetic effects described in the previous paragraphs.

The conversion of heat into electrical energy is demonstrated by the thermocouple, the principle of which is utilized in the pyrometer, an instrument for measuring high temperatures. Heat applied to the junction of two dissimilar metals, for example, iron and copper, Fig. 2, will generate a relatively small electrical voltage across the outer ends. If the two ends are connected by a wire, a current will flow through it from the iron to the copper, as indicated. The voltage produced is due to the difference in the heat conductivity of the two metals and is proportional in value to the difference in temperature of the heated junction and the outer ends. This method of generating current has so far not been proved applicable to the automobile itself, although the pyrometer plays an important part in automobile manufacture, especially in the heat-treating of steel parts.

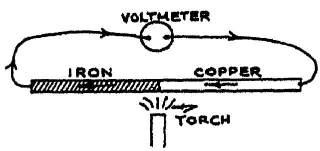


FIG. 2.—The thermo-couple.

The Chemical Electrical Cell.—The production of electric current through chemical action is perhaps the oldest method known for generating electricity. If two different metals are placed in an acid solution which acts chemically upon one metal faster than upon the other, a difference in electrical pressure will be produced and, if these two metals are connected externally by a wire, an electric current will flow through the circuit. This is the basic principle of the dry cell and the storage battery. A cell which consists of a plate of copper and a plate of zinc placed in a 10 per cent solution of sulphuric acid and water is shown in Fig. 3. Since the chemical action of the acid upon the zinc plate is more intense than upon the copper plate, an electric pressure of approximately one volt is set up with the copper-plate terminal positive and the zinc negative. An electric current will be generated and will flow through the wire from the copper

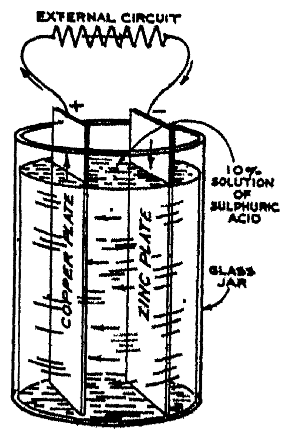


FIG. 3.—Simple voltaic cell.

to the zinc and through the solution from the zinc to the copper, as indicated by the arrows. This chemical cell is often called a *voltaic cell* in honor of Volta, who introduced it.

Electromagnetic Induction.—Electric current may also be generated by passing a wire rapidly through a magnetic field or by moving the field so that it cuts the wire. This principle is utilized in the automobile in the operation of the magneto, the generator and the induction coil. These applications will be taken up at length in later sections.

5. Hydraulic Analogy of an Electric Current.—An electric current flowing through a wire may be compared to the flow of water through a pipe line. The pressure from a pump or a difference in water level, such as from level *A* to level *B* of the tanks represented in Fig. 4, will cause the water to flow. In like manner, an electric current will flow through a conductor, due to the difference in electrical pressure, or *potential*, produced by a cell or battery of cells or by a mechanically driven generator.

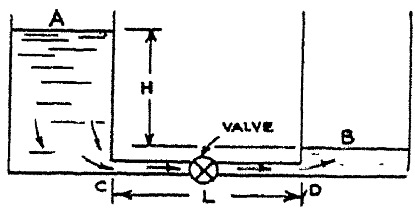


FIG. 4.—Hydraulic analogy of electric current.

As indicated by the arrows in Fig. 3, the current flows from the copper, the high-potential or *positive* (+) terminal, to the zinc, the low-potential or *negative* (−) terminal. In the water circuit the pressure causing the water to flow is measured in pounds per square inch and the rate of flow in gallons per unit of time, while in the electric circuit the pressure or *electromotive force* (sometimes abbreviated e.m.f.) is measured by a unit called a *volt* and the rate of current flow by a unit called an *ampere*.

6. Resistance.—The opposition which a substance offers to the passage of an electric current through it is the resistance of that substance. The unit of this electrical resistance is called an *ohm*. The ohm may be defined as the resistance of a circuit in which one ampere of current will flow under a pressure of one volt. The resistance of a circuit may be compared to the friction offered by a pipe to the flow of a liquid, in that the electrical resistance of the circuit depends upon the size, length, material, and temperature of the conductor, just as the flow of the liquid is resisted by friction, which, in turn, depends upon the

size and length of the pipe, the material or kind of pipe (whether smooth, rough, straight, or crooked), and upon the temperature of the liquid. It is thus evident that the size of a certain wire determines the amount of current it can carry at a given voltage without excessive heating. A small wire can conduct a small current, while a large wire is required to conduct a large current at the same pressure, just as a large pipe is required to conduct a large flow of water. In fact, it has been found that *the resistance of a conductor is directly proportional to its length and inversely proportional to its cross-sectional area.*

The resistance of a conductor depends not only upon its size and length, but also upon the kind of metal of which it is made, since some metals are much better conductors than others. For instance, silver is a better conductor than copper, copper is much better than iron, and iron is much better than lead. Because of its relative cheapness, low resistance, and high-breaking strength, copper is recognized as the best all-round commercial conductor; consequently, it is used universally in the construction and wiring of automotive electrical equipment.

7. Conductors and Non-conductors.—Any substance which offers comparatively low resistance to the flow of current through it is known as a *conductor*. All substances conduct electricity to some extent, yet all offer a certain amount of resistance. The quality of a substance as a conductor, or its *conductivity*, depends upon the material of which it is composed and its purity. A few of the most common conductors used in the automobile, listed in the order of their conductivities, are: silver, copper, aluminum, zinc, brass, platinum, iron, nickel, tin, and lead. A liquid which offers a comparatively low resistance, such as a solution of sulphuric acid and water, is called an *electrolyte*, while a liquid, such as pure water, which offers a high resistance, is known as a *non-electrolyte*. On the other hand, substances which offer high resistances to the passage of electricity through them, for example, glass, mica, rubber, porcelain, fiber, etc., are known as *non-conductors*, or *insulators*. A conductor covered with non-conducting or insulating material, such as rubber, cotton, silk, enamel, etc., is known as an *insulated conductor*.

8. Electrical Units.—The definitions of the principal electrical terms encountered in automotive electrical work are as follows:

Volt.—The practical unit for measuring electrical pressure or electromotive force is the volt. It is the pressure required to force a current of one ampere through a circuit having a resistance of one ohm.

Millivolt.—The millivolt is a term denoting one-thousandth part of one volt.

Ohm.—The ohm, or unit of electrical resistance, may be defined as the resistance offered by a circuit to the flow of one ampere flowing under a pressure of one volt. From a practical point of view, it may be remembered that the resistance offered by 1,000 ft. of No. 10 B. & S. gage copper wire (approximately 1/10 in. in diameter) is almost exactly one ohm (see resistance table, page 10).

Ampere.—The ampere, or unit of electrical current, may be defined as the rate at which current will flow through a circuit with a resistance of one ohm under a pressure of one volt. If the above-mentioned copper wire, for example, having a resistance of one ohm, were connected between the plates of the voltaic cell shown in Fig. 3, which produces a pressure of one volt, one ampere would flow through the wire.

Ampere-hour.—The term *ampere-hour* denotes the quantity of electricity equal to one ampere flowing for a period of one hour. Thus, the product of the current in amperes and the time in hours equals ampere-hours, or

$$\text{Ampere-hours} = \text{Amperes} \times \text{Hours}. \tag{1}$$

Watt.—The watt, or unit of electrical power, is the rate at which work is performed by one ampere of current flowing under a pressure of one volt. The watts are equal to the volts multiplied by the amperes, or

$$\text{Watts} = \text{Volts} \times \text{Amperes}. \tag{2}$$

Watt-hour.—One watt of power used for a period of one hour equals one watt-hour. Thus, the watt-hours are equal to the volts multiplied by the amperes and the hours or

$$\text{Watt-hours} = \text{Volts} \times \text{Amperes} \times \text{Hours}. \tag{3}$$

Kilowatt.—The watt in many instances is too small a unit for convenient use; consequently, the *kilowatt*, which equals 1,000 watts, is frequently used; thus

$$1 \text{ kilowatt} = 1{,}000 \text{ watts}. \tag{4}$$

Kilowatt-hour.—One kilowatt of power used for one hour equals one kilowatt-hour; thus

$$\text{Kilowatt-hours} = \text{Kilowatts} \times \text{Hours} \tag{5}$$
$$= \frac{\text{Volts} \times \text{Amperes} \times \text{Hours}}{1{,}000}$$

9. Relation between Current, Voltage, and Resistance.—A definite relation exists between the current flowing, the voltage, and the resistance of the circuit. This relation is known as *Ohm's law;* namely, *the electric current in a conductor equals the voltage applied to the conductor divided by the resistance of the conductor.* This law may be simply stated

$$\text{Current} = \text{Voltage} \div \text{Resistance}$$

or
$$\text{Amperes} = \text{Volts} \div \text{Ohms}$$

or, representing the law by use of symbols:

To find *current:*

$$I = \frac{E}{R}, \tag{6}$$

in which I is the current in amperes, E is the voltage or electromotive force in volts, and R is the resistance in ohms.

By transposing, this formula may also be expressed for more convenient use as follows:

To find *voltage:*

$$E = I \times R \tag{7}$$

To find *resistance:*

$$R = \frac{E}{I}. \tag{8}$$

10. The Voltmeter and Ammeter.—The voltage and current of a circuit can be readily measured by connecting a *voltmeter* and an *ammeter*, respectively, as shown in Figs. 5 and 6. Although the two instruments are usually very similar in external appearance, the voltmeter is designed to measure the electrical pressure in volts and is connected across the source of current supply, such as terminals A and B, Fig. 5, while the ammeter is an instrument for measuring the current flow in amperes and is connected in the circuit as in Fig. 6, so that the current flowing in the circuit passes through the instrument. Only the ammeter is usually supplied on the automobile, the voltmeter being used chiefly for testing purposes. The ammeter is usually of the type shown

in Fig. 7. It is located on the instrument board and is connected in the lighting and battery-charging circuits so that it will indicate the amount of current either charging or discharging from the battery.

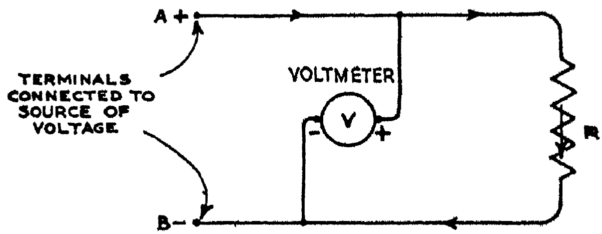


FIG. 5.—Method of connecting voltmeter to test voltage of a circuit.

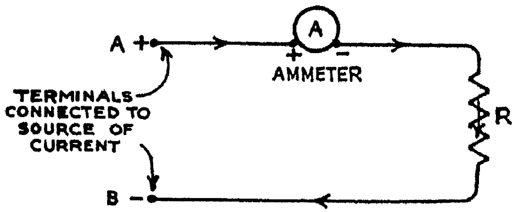


FIG. 6.—Method of connecting ammeter to test current flowing in a circuit.

As there is no convenient instrument for measuring directly the electrical resistance of a circuit, this must be calculated by first measuring the voltage and current as just described and dividing the voltage in *volts* by the current in *amperes* as in formula (8).

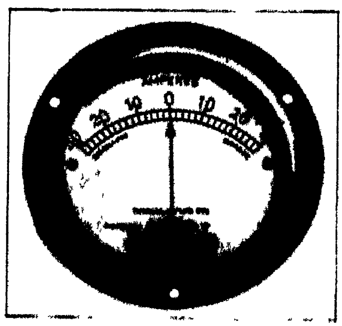


FIG. 7.—Typical automobile dash type ammeter.

11. Resistance of Copper Wire.—The following table gives the various sizes of copper wire, the number of feet per pound for bare wire, and the resistance per 1,000 ft. at 68 deg. F. and at 122 deg. F. respectively. It also gives the weight per 1,000 ft. of double-cotton-covered magnet wire, including all standard sizes from Nos. 8 to 40 (B. & S. gage) used for winding coils, armatures, etc. From this table it will be noted that the resistance increases as the size of the wire decreases, and increases with an increase in temperature. The change in resistance due to an increase in temperature can be seen by comparing the last two columns of the table.

RESISTANCE OF STANDARD ANNEALED COPPER WIRE
American Wire Gage (Brown & Sharpe)

Gage	Diameter of wire in inches	Feet per pound (bare wire)	Weight per 1,000 ft in pounds D.C.C. magnet wire	Ohms per 1,000 ft. 20 deg. C (68 deg. F.)	Ohms per 1,000 ft. 50 deg. C (122 deg. F.)
0	0.3249	3.130	. . .	0.09827	0.1099
1	0.2893	3.948	. . .	0.1239	0.1385
2	0.2576	4.978	. . . .	0.1563	0.1747
3	0.2294	6.276	. . .	0.1970	0.2203
4	0.2043	7.911	. . . . . .	0.2485	0.2778
5	0.1819	9.980	. . . . . .	0.3133	0.3502
6	0.1620	12.58	. . . . .	0.3951	0.4416
7	0.1443	15.87	. . . . .	0.4982	0.5569
8	0.1285	20.01	51.15	0.6282	0.7023
9	0.1144	25.23	40.60	0.7921	0.8855
10	0.1019	31.82	32.18	0.9989	1.117
11	0.0907	40.13	25.60	1.260	1.408
12	0.0808	50.58	20.40	1.588	1.775
13	0.0719	63.77	16.20	2.003	2.239
14	0.0641	80.45	12.91	2.525	2.823
15	0.0571	101.4	10.33	3.184	3.560
16	0.0508	127.9	8.210	4.016	4.489
17	0.0453	161.3	6.540	5.064	5.660
18	0.0403	203.4	5.235	6.385	7.138
19	0.0359	256.5	4.220	8.051	9.001
20	0.0320	323.4	3.373	10.15	11.35
21	0.0285	407.8	2.685	12.80	14.31
22	0.0253	514.2	2.168	16.14	18.05
23	0.0226	648.5	1.727	20.36	22.76
24	0.0201	817.7	1.398	25.67	28.70
25	0.0179	1,031.0	1.129	32.37	36.18
26	0.0159	1,300.0	0.9140	40.81	45.63
27	0.0142	1,639.0	0.7560	51.47	57.53
28	0.0126	2,067.0	0.6075	64.90	72.55
29	0.0113	2,606.0	0.4890	81.83	91.48
30	0.0100	3,287.0	0.3955	103.2	115.4
31	0.0089	4,144.0	0.3257	130.1	145.5
32	0.0080	5,227.0	0.2700	164.1	183.4
33	0.0071	6,591.0	0.2270	206.9	231.3
34	0.0063	8,312.0	0.1928	260.9	291.7
35	0.0056	10,480.0	0.1600	329.0	367.8
36	0.0050	13,213.0	0.1361	414.8	463.7
37	0.0045	16,664.0	0.1204	523.1	584.8
38	0.0040	21,012.0	0.1049	659.6	737.4
39	0.0035	26,497.0	0.0937	831.8	929.8
40	0.0031	33,411.0	0.0838	1,049.0	1,173.0

By a study of this table it will also be seen that a wire that is three sizes smaller than another wire has approximately one-half the weight and offers twice the resistance per given length. On the other hand, a wire that is three sizes larger will have twice the weight and one-half the resistance. Thus, if the weight and the resistance of a certain size wire, for example, No. 10, which weighs 32.18 lb. and has a resistance of approximately one ohm per 1,000 ft., can be remembered, many of the common sizes used in automotive work, namely, Nos. 13, 16, 19, 22, 25, etc., can be readily figured as having a resistance of 2, 4, 8, 16, 32, etc. ohms respectively. These values are close enough for most practical purposes.

12. Resistance of Nichrome Wire.—The universal material used for resistance units and heating elements is an alloy of nickel and chromium known as *nichrome*. It is a patented wire, valuable on account of its high specific resistance and its durability. Nichrome has about fifty times the resistance of copper wire. The following table gives the resistance per 1,000 ft. of nichrome wire for the common sizes used, ranging from Nos. 16 to 35, B. & S. gage:

PROPERTIES OF NICHROME RESISTANCE WIRE (DRIVER-HARRIS COMPANY)

Resistance per Mil-foot = 600 ohms at 75 deg. F. (24 deg. C.)
Temperature Coefficient = 0.00024 per degree Fahrenheit
Specific Gravity = 8.15
Weight per cubic inch = 0.29 lb.

B & S No.	Diameter in inches	Area in circular mils. C M = D^2	Resistance in ohms per 1,000 ft at 75 deg. F	Weights per 1,000 ft (bare)	Ohms per pound
16	0.051	2,601	230	7.2	31
17	0.045	2,025	296	5.6	52.8
18	0.040	1,600	375	4.42	84.8
19	0.036	1,296	463	3.58	129
20	0.032	1,024	586	2.83	207
21	0.0285	812.3	738	2.24	329
22	0.0253	640.1	937	1.77	529
23	0.0226	510.8	1,174	1.41	832
24	0.0201	404.0	1,485	1.12	1,323
25	0.0179	320.4	1,872	0.89	2,100
26	0.0159	252.8	2,373	0.70	3,390
27	0.0142	201.6	2,971	0.56	5,300
28	0.0126	158.8	3,778	0.44	8,580
29	0.0113	127.7	4,698	0.35	13,400
30	0.010	100.0	6,000	0.276	21,700
31	0.0089	79.2	7,575	0.219	34,500
32	0.008	64.0	9,375	0.177	52,900
33	0.0071	50.4	11,904	0.139	85,600
34	0.0063	39.7	15,113	0.11	137,000
35	0.0056	31.4	19,108	0.087	219,000

13. Effect of Temperature on Electric Resistance.—It will be found by reference to the tables for copper and nichrome wire, that the resistance of a wire of either material varies with the temperature. This is true of practically all substances. With most metal conductors, an increase in temperature results in an increase in resistance. With insulating materials, carbon, and various electrolytic solutions, an increase in temperature is accompanied by a decrease in resistance. These facts are important and should be kept in mind when considering the performance of generators, spark plugs, batteries, charging rheostats (variable-resistance units), etc., under different temperature conditions.

14. Electrical Power.—The unit of electrical power is the *watt*. It may be defined as *the rate at which work is performed by a current of one ampere flowing under a pressure of one volt.* Expressed as a formula:

$$P = E \times I \tag{9}$$

in which

$E =$ electrical pressure in volts
$I =$ the current in amperes
$P =$ the power in watts.

Likewise, by transposing:

$$I = \frac{P}{E} \tag{10}$$

and

$$E = \frac{P}{I}. \tag{11}$$

It may be seen from formula (9) that, if the voltage applied to a circuit and the current flowing in it are known, the electrical power in watts may be readily determined by multiplying the voltage in volts by the current in amperes. As an example: If the primary circuit of an automobile ignition system draws a continuous current of 2½ amp. from a 6-volt battery (as indicated by the dash ammeter), the electrical power or work required of the battery will be $P = E \times I$, or $6 \times 2\frac{1}{2} = 15$ watts.

In many cases the watt is too small a unit for convenient use; consequently, the kilowatt (kw.), or 1,000 watts, is frequently

used. It requires 746 watts to equal one mechanical horsepower (hp.), therefore,

$$1 \text{ kw.} = \frac{1{,}000 \text{ (watts in 1 kw.)}}{746 \text{ (watts in 1 hp.)}}, \text{ or } 1.34 \text{ hp.}$$

and

$$1 \text{ hp.} = \frac{746 \text{ (watts in 1 hp.)}}{1{,}000 \text{ (watts in 1 kw.)}}, \text{ or } 0.746 \text{ kw.}$$

Approximately, 1 kw. equals $1\frac{1}{3}$ hp. and 1 hp. equals $\frac{3}{4}$ kw.

15. Electrical Circuits Defined.—The various types of circuits may be defined as follows:

Closed Circuit.—A circuit is said to be a closed circuit when the circuit is complete or closed, permitting the current to flow through it.

Open Circuit.—A circuit is said to be an open circuit when the circuit is broken or open, thus preventing current from flowing through it.

External and Internal Circuits.—That part of a circuit which is external to the electrical source, for example, a generator or battery, is called the external circuit, while the remaining part of the circuit within the electric source is called the internal circuit.

Short Circuit.—A short circuit is one in which the path of the current has been shortened so that the circuit thus formed offers practically no resistance in comparison to the rest of the circuit.

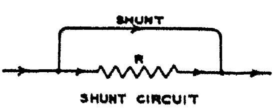


FIG. 8.—Shunt circuit.

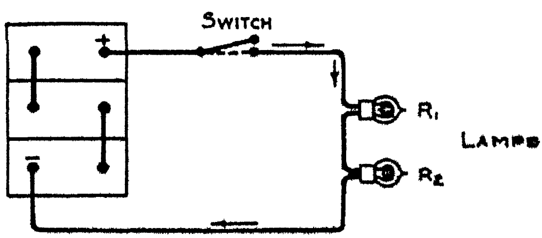


FIG. 9. Lamps connected in series.

Ground Circuit.—A ground circuit on an automobile is a circuit in which the engine or car frame forms a part of the circuit, thus taking the place of one wire. The ground connection of the circuit to the car frame is indicated by the symbol ⏚.

Shunt Circuit.—A circuit which branches out from the main circuit, runs parallel to it for a short distance, and then reenters the main circuit, as in Fig. 8, is termed a shunt circuit.

Series Circuit.—When two or more electrical devices or resistances are connected so that the same current must flow through each, the devices or resistances are connected in series and the circuit is known as a series circuit. Figure 9 shows two lamps connected in series with a storage battery.

16. Resistance of a Series Circuit.—The resistance in ohms of a series circuit is equal to the sum of all the resistances of the various devices connected in the circuit, or

$$R = R_1 + R_2 + R_3, \text{ etc.} \tag{12}$$

where R equals total resistance in ohms and R_1, R_2, and R_3 equal the respective resistances of the various devices connected in the circuit.

For example, if R_1 and R_2, Fig. 9, represent two 6-volt lamps connected in series, the filament of each being of such material, size, and length as to offer a resistance of 2 ohms, the total resistance offered by the lamps will be R_1 plus R_2, or $2 + 2 = 4$ ohms. The current which the lamp circuit will draw from a 6-volt battery will then be, according to formula (1),

$$I = \frac{E}{R} = \frac{6}{4} = 1\tfrac{1}{2} \text{ amp.}$$

If the lamps connected in this manner are both of the same kind, for example, 6-volt, 18-cp., each will burn at one-half voltage and, consequently, with a correspondingly reduced brilliancy.

17. Parallel Circuits.—When two or more circuits are connected to the same source of current supply, thus providing more than one path for the current to flow along, as in Fig. 10, the circuits are said to be connected in parallel. It is evident that the more paths there are for the current to travel in the less will be the total resistance and the greater will be the current flowing in the combined circuits. It will also be seen that the amount of current flowing in each parallel circuit will be in proportion to the resistance of that circuit. For example, if two circuits having resistances of 10 ohms and 1 ohm respectively are connected in parallel, as in Fig. 11, the current flowing in the circuits will be in proportion to the resistances of the two circuits, or a ratio of 10 to 1. Thus, if a total current of 11 amp. is flowing through the two circuits, the 10-ohm circuit will conduct 1 amp. and the 1-ohm circuit 10 amp.

The total resistance of two or more parallel circuits may be determined from the following formula:

$$R = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \text{etc.}} \qquad (13)$$

in which R_1, R_2, R_3, etc. represent the resistances of the various circuits connected in parallel. As an example, assume that the

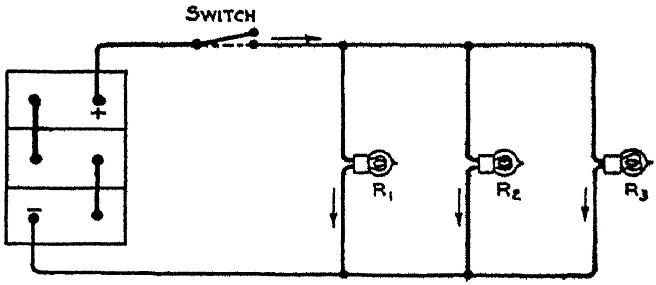


FIG. 10.—Lamps connected in parallel.

lamps R_1, R_2, and R_3 in Fig. 10 have resistances of 8, 4, and 2 ohms, respectively; then by formula (13) the combined resistance of the three lighting circuits will be

$$R = \frac{1}{\frac{1}{8} + \frac{1}{4} + \frac{1}{2}} = \frac{1}{\frac{7}{8}} = \frac{8}{7}, \text{ or } 1.143 \text{ ohms.}$$

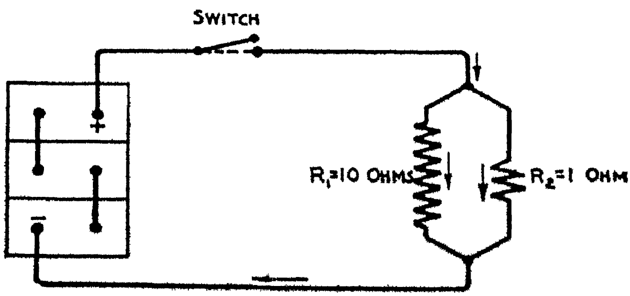


FIG. 11.—Parallel circuits.

The total current drawn by all the lamps, if connected to a 6-volt storage battery, as shown, may now be found by formula (1).

$$I = \frac{E}{R'}, \text{ or } \frac{6}{1.143} = 5.25 \text{ amp.}$$

By connecting the lamps in parallel, each lamp will operate at the same voltage (the voltage of the battery) and independent

of the other lamps. If one lamp is turned off, or burned out, the other lamps will not be effected, but will continue to burn with full brilliancy. This, however, would not be the case if the lamps were connected in series as in Fig. 9, since the burning out of one lamp would open the entire circuit and prevent current from flowing through the other lamp.

18. Primary and Secondary Cells.—A chemical cell may be defined as an assembly of two dissimilar elements in contact with an electrolyte. Electrical voltage is produced from such a cell

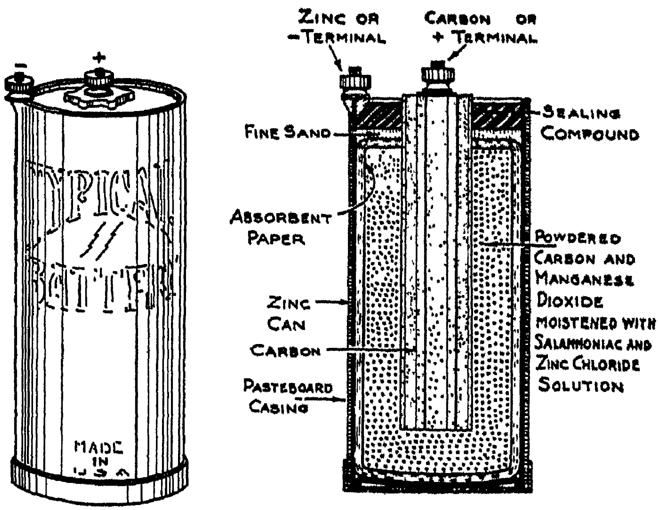


Fig. 12.—Construction of typical dry cell.

because the chemical action of the electrolyte is more intense on one plate than on the other.

Primary Cells.—A primary cell may be classified as either *wet* or *dry* according to its construction. In the wet cell, the electrolyte is in the form of a liquid, Fig. 3, while in the dry cell it is in the form of a wet paste which will not flow or splash. A wet cell, owing to its low voltage (usually about 1 volt) and the relatively small current output in proportion to its size and weight, is very inconvenient for automotive ignition purposes. For this service the dry cell, Fig. 12, has been used extensively, since it gives a much higher voltage and current output (1½ volts and 25 to 30 amp. when the cell is new) and is much more convenient to handle than a wet cell. Even the dry cell, however, has almost dis-

appeared from automotive service, being replaced by the magneto and the storage battery.

The chief characteristic of any primary battery is the fact that, as electrical energy is produced, one of the elements is destroyed by the chemical action. Thus when a primary cell has become exhausted, it can be replenished only by renewing either the elements or the electrolyte or both. In the dry cell, it is more convenient, and much cheaper, to replace the entire cell with a new one.

Secondary Cells.—The secondary cell, commonly known as a *storage cell* or *battery*, differs from the primary battery in that it may be charged and discharged many times without renewing either the elements or the electrolyte. A secondary cell must first be charged by sending a direct current through it, thereby causing the elements to undergo an electrochemical change; then, when the cell is used as a source of current, the current discharge is accompanied by a reverse chemical change. A cell of this type can be used repeatedly by providing a means of recharging when it becomes exhausted or discharged.

The storage battery as used for automobile service is treated more fully in Secs. XIII, XIV, XV, and XVI.

19. The Dry Cell.—The dry cell was used very extensively in the early days of automobile ignition and is still used to some extent for tractor, truck, and stationary-engine ignition, although the storage battery and the magneto are rapidly supplanting it as sources of current.

The construction of a typical dry cell is shown in Fig. 12. It consists of a cylindrical zinc shell or can, the inside of which is lined with absorbent paper saturated with a solution of sal ammoniac and zinc chloride. The zinc shell forms the negative terminal of the battery and the carbon rod placed in the center of the cell forms the positive terminal. The space between the absorbent paper and the carbon rod is filled with a mixture of crushed carbon and manganese dioxide. This mixture is saturated with sal ammoniac and zinc chloride. The purpose of the crushed carbon and manganese dioxide mixture is to act as a depolarizing agent.

Polarization.—The term *polarization* refers to the accumulation of hydrogen gas liberated from the electrolyte (sal ammoniac and zinc chloride), which tends to form as gas bubbles around the carbon or positive element

when the cell discharges rapidly. The gas thus formed tends to insulate the carbon rod from the electrolyte, thereby increasing the internal resistance of the cell and diminishing the current output. The manganese dioxide, which is rich in oxygen, acts to depolarize or absorb this gas by the combining of the oxygen and hydrogen, forming water.

Nearly all American dry cells used for ignition are 2½ in. in diameter and 6 in. high. This size is usually referred to as No. 6. The top is sealed with a special compound to make the cell air- and water-tight. The entire cell, except the top, is wrapped with pasteboard to prevent the zinc from making metallic contact with other cells in the set. The voltage of a good dry cell on open circuit is about 1½ volts. The maximum current or amperage which it will give, when new, ranges from 20 to 35 amp., depending upon the size of the cell and the temperature. A No. 6 cell, giving more than 25 to 30 amp., will probably polarize rapidly. Cell capacity and life depend largely on the way the cell is used. In fact, both will be greater when it is used intermittently. *The dry cell gives out direct current.*

Not all dry cells are suitable for ignition. Cells which may be suitable for intermittent use on door bells, annunciators, telephones, etc. may have a rather high internal resistance. Ignition cells should be constructed so as to have a low internal resistance.

20. Testing Dry Cells.—The standard method of testing dry cells is by an ammeter. This instrument indicates the rate of flow of current in amperes. Figure 13 shows a combination voltmeter and ammeter, known as a volt-ammeter, such as is usually used for dry-cell testing. The flexible terminal is in both the ammeter and voltmeter circuits. When used to test the current of dry cells, the flexible terminal and the terminal marked "Amps." are touched to the dry-cell terminals, the stationary terminal being connected to the center terminal or positive and the flexible terminal to the zinc or negative. The needle will move across the scale and indicate the current strength of the cell. When new, the reading for a No. 6 ignition cell should be between 25 to 30 amp. If the reading falls below 8, it shows that the cell is nearly exhausted and cannot be considered as a reliable source of energy.

There is a perceptible difference in the action of dry cells at various temperatures. It is difficult for the chemical action to take place fast enough at a temperature of zero or below; consequently, the cell will test lower than at normal temperatures. On the other hand, heat stimulates the chemical activity causing the cell to test higher than at normal temperatures. Heat will also cause a rapid deterioration of dry cells; consequently, when

not in use they should be stored in a cool, dry place to prevent rapid deterioration.

A rough test to determine if a cell is good can be made by short-circuiting the terminals momentarily by a wire. If a small arc can be drawn between the wire and the carbon post, the cell is at least in fair condition. The test can also be made by stretching a piece of fine copper wire of about No. 28 or 30 gage across the terminals. If it fuses instantly, it proves that the cell will test between 15 and 20 amp., if tested with an ammeter. Another

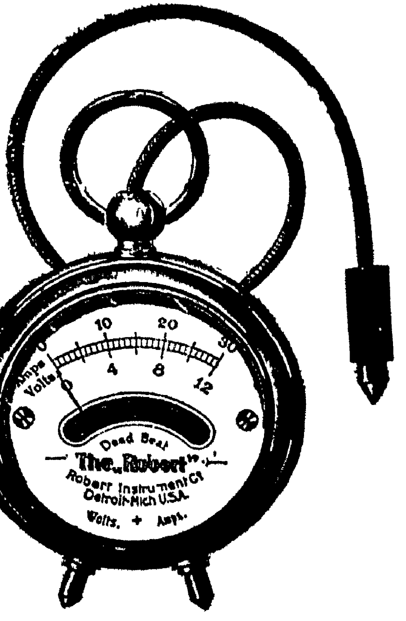


Fig. 13 Typical volt-ammeter suitable for testing dry cells.

method is to rest a knife blade on the zinc post and to touch the tip of the blade to the carbon. If a small ring of smoke appears at the point, the cell is in fair condition.

21. Wiring of Dry Cells.—When dry cells are used for ignition, they may be connected either in *series* or in *parallel*. The series method of connection is shown in Fig. 14, in which the carbon or *positive* of one cell is connected to the zinc or *negative* of the next, leaving one carbon and one zinc free for connection. Thus the current has to pass through the entire set of cells to complete its circuit. This method increases the voltage as many

Soft iron after being magnetized loses its magnetism rapidly after the magnetizing force is removed and is consequently called a *temporary* magnet. A bar of hardened steel after being magnetized will, with proper treatment, remain magnetized almost indefinitely, and is, consequently, called a *permanent* magnet. For this reason, temporary magnets, such as those used in the cores of induction coils, are made of soft iron—usually a bundle of soft-iron wire—while permanent magnets, such as the magnets of a magneto, are made of hardened steel of suitable quality.

25. The Poles of a Magnet. Certain parts of a magnet possess the power of attracting iron to a much greater extent than

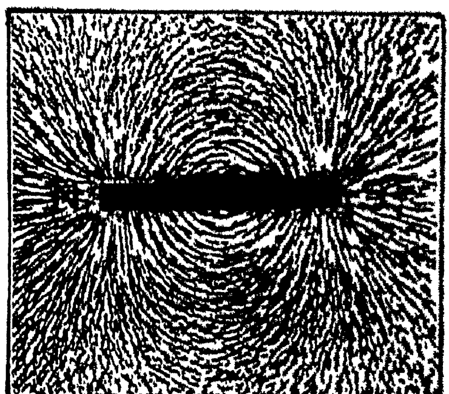


FIG. 17.—Field produced by straight bar magnet.

other parts. These parts are called the *poles*. In a bar magnet the strength is greatest at the ends, consequently the ends form the poles. These poles are designated *north* and *south*, according to their magnetic influence on other magnets, and according to the direction of the magnetism.

It is generally understood that magnetism acts in the nature of a stream or current. This flow of magnetism is termed magnetic *flux* and is conventionally represented by *lines of force* which always flow out of the *north* pole of a magnet and around into the *south* pole, forming a complete circuit. This action may be readily seen by placing a piece of paper over a bar magnet and sprinkling iron filings over the paper. The magnetic force will arrange the filings in lines running from one end of the magnet around to the other end as shown in Fig. 17.

Furthermore, when two magnets are brought together, it is found that the north pole of one attracts the south pole of the other and that two like poles, either north and north or south and south, repel each other. Magnetic attraction and repulsion may be shown by dipping two common magneto magnets in iron filings and noting the formation of the filings when the poles of the two are brought together. With the north and south poles brought together, as in Fig. 18, the iron filings will form in metallic strings between

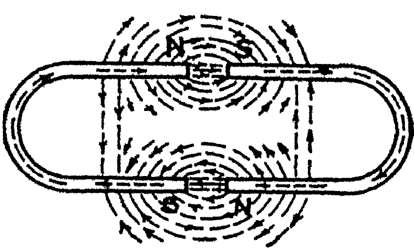


FIG. 18. Attraction between magnets when unlike poles are brought together

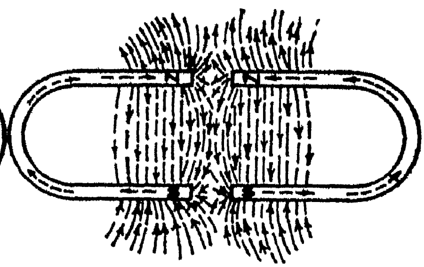


FIG. 19 — Repulsion between magnets when like pole are brought together.

the poles, thus showing magnetic attraction. With the like poles brought together, as in Fig. 19, the filings will have the appearance of two jets of water being forced against each other and will show repulsion. In each case the iron filings plainly indicate the path of the magnetic circuit which is flowing within the magnet from the south (*S*) to the north (*N*) pole and through the space between the poles from the north (*N*) to the south (*S*) pole

26. The Magnetic Field. The zone surrounding a magnet through which the magnetism passes in flowing from the north

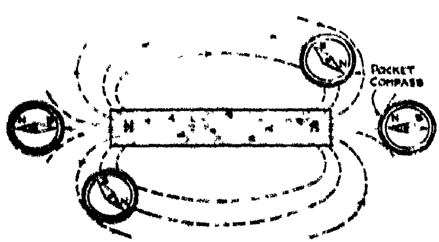


FIG. 20. Testing polarity of magnet using compass.

pole to the south pole is known as its *magnetic field*. The strength of this field depends upon the number of magnetic lines of force per square inch of the magnet poles and is usually measured in pounds' pull per unit area of the pole.

The polarity of a magnet and the direction of its magnetic field may be readily determined by a compass, as shown in Fig. 20. The north end of the compass needle (the end which naturally points toward the earth's geographical north pole) will always point in the direction of the magnetic lines of force or toward the south pole of the magnet. Likewise, the south end of the compass needle will point toward the north pole of the magnet.

27. The Earth's Magnetic Field.—The presence and the influence of the earth's magnetic field are readily indicated by suspending a bar magnet or magnetized needle either on a pivot or by a fine string or hair so that it will swing freely, and noting the position it will take with respect to the earth's axis. If not influenced by other magnets or bodies of iron, the suspended magnet will seek a north and a south position; that is, the north end of the magnet will point in the general direction of the earth's geographical north pole. As a matter of fact, the north end of the magnet is attracted by the magnetic *south* pole of the earth, which is located in the extreme northern part of the Hudson Bay district, Canada, a point approximately 500 to 1,000 miles from the geographical north pole. The opposite or south end will be attracted by the magnetic north pole of the earth which is similarly located with respect to the geographical south pole. Thus the suspended magnet or compass seeks a position parallel to the magnetic lines of force of the earth's field which may or may not be in line with the north and south geographical poles. It should be remembered, however, that the end of the magnet or needle which turns toward the geographical north is actually the north pole of the magnet. With the polarity thus determined, the magnet can then be used in testing other magnets, since unlike poles attract and like poles repel.

28. The Molecular Theory of Magnetism.—Although it is not definitely known just what magnetism is, the most satisfactory explanation yet advanced is the *molecular theory*. By this theory it is assumed that the magnetic material, whether soft iron or steel, is composed of an infinitely large number of molecules, each molecule being a miniature magnet having a north and a south pole.

It will be found that, if a bar magnet is broken into many pieces, each piece will have a north and a southas pole, indicated in Fig. 21. According to the molecular theory, the molecules

in a piece of iron not magnetized have a disorderly arrangement, as shown in Fig. 22, the small molecular magnets having a neutralizing effect on each other, so that the bar as a whole does not show any magnetizing effect. When the bar is magnetized, the molecules of iron turn like small compass needles in the direction of the magnetizing force, arranging themselves with all like poles pointing in the same direction, as shown in Fig. 23.

In a steel bar the molecules are compressed much more tightly together than in soft iron. This accounts for the fact that steel

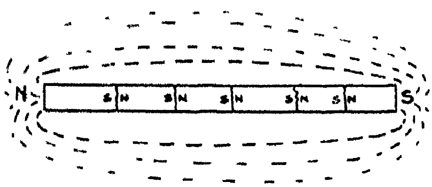


FIG. 21. Polarity of pieces when magnet is broken.

is slower to magnetize than soft iron, but holds its magnetism longer. Once this arrangement of the steel molecules is attained, most of them will retain the new position, and a permanent magnet is the result; while with soft iron most of the molecules will quickly return to their previous disorderly arrangement and the bar loses its magnetic effect. In line with this theory it will be found that striking the bar a stinging blow with a hammer to vibrate the molecules, while the magnetizing force is applied, will aid materially in turning the molecules and will produce

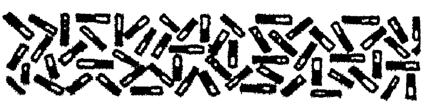


FIG. 22.—Arrangement of molecules with bar not magnetized.

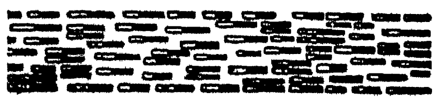


FIG. 23.—Arrangement of molecules with bar magnetized.

stronger magnetic effects. This is especially true with steel. On the other hand, striking the magnet after the magnetizing force has been removed will have the effect of disarranging the molecules, resulting in the bar losing part of its strength. Heating a magnet will also cause it to become demagnetized, due to the vibrating and disarranging of the molecules by heat. This fact also gives strength to the molecular theory.

A demonstration of the molecular theory of magnetism may be made by holding a piece of ordinary gas pipe, say 3 to 4 ft. long, in a north and south position and striking it several stinging blows with a hammer. A test for magnetism should then be made with a sensitive pocket compass. It will be found that the end of the pipe pointing toward the geographical north (magnetic south pole) will show north magnetic polarity, while the opposite end will show south. If the pipe is reversed in position and the pounding repeated, the magnetism in the pipe will be reversed and the end which previously tested north will test south. If the pipe were held, however, in an east-and-west position, no change in polarity would be noticed. This experiment, therefore, shows that the earth's magnetic field passes from south to north (geographically) and is of sufficient strength to magnetize slightly an iron bar when held in this position provided the molecules are assisted in rearranging themselves through vibration.

29. Magnetic Induction. When a piece of soft iron is brought into the magnetic field of another magnet, the iron itself becomes a temporary magnet with north and south poles as shown in Fig. 24. The magnetizing effect thus produced is known as *magnetic induction.*

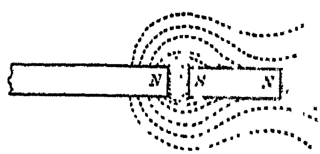


FIG. 24.—Principles of magnetic induction.

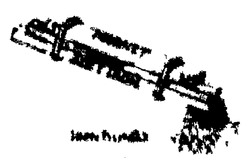


FIG. 25.—Magnetic induction through non-magnetic material.

Magnetic induction takes place when the body is brought into contact with or separated from the magnet. Magnetic induction may also take place through all non-magnetic substances, whether they are solids, liquids, or gases. One pole of the magnet induces the opposite pole in the other body under induction nearest to the inducing pole, and a like pole at the other end, as indicated in Fig. 24.

The principle of magnetic induction can further be demonstrated by binding a bar magnet to a piece of soft iron (not a magnet), the two being separated by a wooden strip, as shown in Fig. 25. When the soft iron is dipped in iron filings, it will be observed that, under the influence of the bar magnet, the iron becomes a temporary magnet by magnetic induction—the result of temporary alignment of the molecules in the soft-iron bar by the magnetic field of the magnet passing through it. Magnetic induction, therefore, takes

place between iron bodies even when separated by wood or other non-magnetic substances. In fact, it is considered impossible to insulate against magnetism.

30. Magnetic Permeability and Saturation.—The ability of a magnetic material (iron or an iron alloy) to conduct magnetism is known as its *magnetic permeability*. The value of the magnetic permeability will depend upon the character of the substance and the magnetizing force. Good wrought iron or mild steel, for example, will conduct much more magnetism per square inch than cast iron, etc. In fact, the permeability of magnetic materials varies with the character of the material, just as the electrical conductivity of metals, for example, silver, copper, aluminum, lead, etc., will vary, depending upon the materials of which the conductor is composed.

In the case of a vacuum; air; non-magnetic materials, as silk, cotton, and other insulators; brass; copper, aluminum and other non-magnetic metals; the permeability may be taken as unity, or 1. In comparison, therefore, magnetic metals will have a permeability of greater than 1, and in the case of soft iron may reach 3,000. That is, soft iron, if of proper quality, may conduct magnetism 3,000 times better than air.

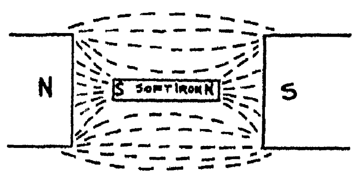


FIG. 26. Comparative permeability of iron and air.

When a piece of iron or steel is placed between the poles of a magnet, as in Fig. 26, a large per cent of the magnetism will pass through the iron, as indicated, because the iron has greater permeability than the air. When the iron has been magnetized up to a certain degree, however, it becomes less and less subject to further magnetization. Finally, it will tend to reach the *magnetic saturation* point of the metal, that is, the iron will be conducting all the magnetism it can possibly carry per square inch of its cross-sectional area. Thus, the point at which magnetic saturation is reached depends upon the permeability.

31. Residual Magnetism and Retentivity.—That property of a magnetic material (iron and steel) to retain magnetism after the magnetizing force has been removed is known as its *retentivity*, while the magnetism which it retains is known as *residual magnetism*.

The extent of the residual magnetism retained by a magnet, and its ability to hold this magnetism, depend both upon the quality of the magnet and its hardness. If, for example, a bar of soft steel is magnetized, it will make a stronger magnet while the magnetizing force is applied than will a bar of hard steel. But the instant the magnetizing force is removed the soft steel will lose practically all of its magnetism, while the hard steel will retain a relatively large amount. Thus, the hard steel has greater retentivity. Soft iron or steel, therefore, cannot be used to make permanent magnets; in fact, hardened nickel, chrome or tungsten steels are generally used for the permanent magnets on magnetos.

32. Electromagnetism.—Magnetism which is produced by an electric current is called *electromagnetism*. Experiments show that *a wire or any other form of conductor which carries an electric*

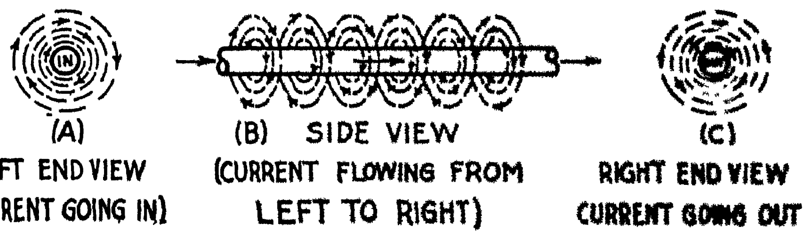


FIG. 27.—Magnetic lines of force about a straight conductor carrying current.

current will have a magnetic field set up around it in a right-handed direction with respect to the flow of current and proportional in strength to the amount of current flowing. This fact constitutes the basis for the relation between electricity and magnetism. The magnetic field thus produced is arranged in concentric circles around the wire as in Fig. 27, and, like the field of a magnet, its direction can be determined by a pocket compass. The magnetic needle, if held above or below a wire carrying a direct current, will turn crosswise of the wire, as in Fig. 28, with the north end of the compass pointing around the wire in the direction of the magnetic lines of force. Thus, by determining the direction of the magnetic field around the wire, the direction of current flowing in the wire may also be determined.

If the wire is coiled into a loop, as in Fig. 29, it will be found that the lines of force all enter the same face of the loop and come out of the other face.

If two loops are placed close together, as in Fig. 30A, the lines of force will join and go around the two wires together instead of around each one alone. The same is true of the lines of force surrounding two parallel wires placed

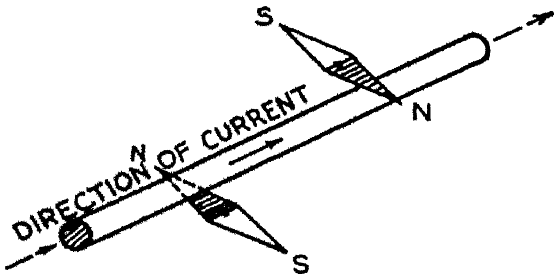


FIG. 28. Deflection of a compass needle when near a conductor carrying a current.

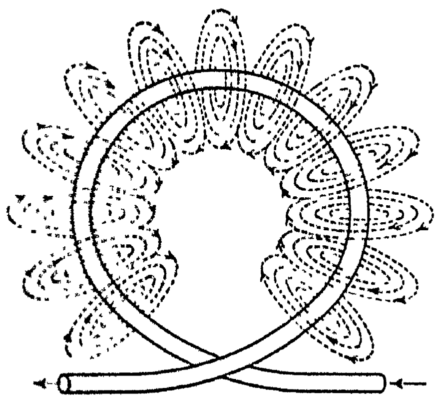


FIG. 29. Magnetic field produced by current in a single loop.

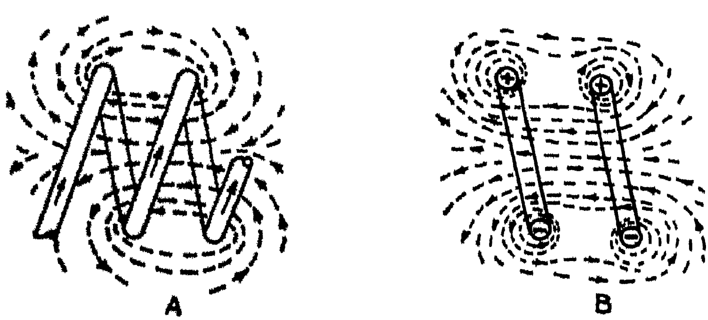


FIG. 30.—Magnetic lines of force about two adjoining loops carrying current in the same direction.

close together, in which both wires are carrying current in the same direction as in Fig. 30B. If a number of turns of insulated wire are wound into a

coil or *solenoid*, as in Fig. 31, nearly all the lines of force will enter one end of the coil, pass through it, leave the opposite end, and return outside the coil to the starting point. Thus, a solenoid or coil carrying an electric current has the same character of magnetic field as a bar magnet. It has a north pole where the lines of force leave the coil and a south pole where the lines of force enter the coil. It may, therefore, be considered an *electromagnet*.

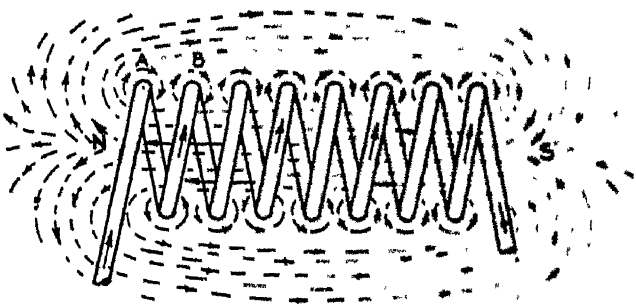


FIG. 31.—Lines of force through a coil or solenoid.

33. The Electromagnet.—An electromagnet made as just described is not very strong, but may be made so by inserting a core of soft iron or steel as in Fig. 32. The iron has the property of conducting magnetic lines many times more readily than the air; hence, a solenoid with an iron core will have much greater strength than a simple solenoid without a core.

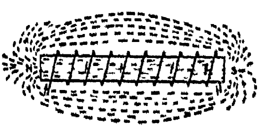


FIG. 32.—Lines of force through an electromagnet—inductive wound.

34. Strength of Electromagnets.—The strength of an electromagnet may also be increased by increasing either the amount of current flowing through the winding or the number of turns in the coil, or both. In fact, the magnetic pull of the core will depend not only on the size and length of the core but on the number of amperes multiplied by the number of turns in the winding, or the total number of *ampere-turns* producing the magnetism. In Fig. 32, if the coil consists of 10 turns of wire, through which a current of 8 amp. is flowing, the magnetic pull of the core will be due to 8 × 10, or 80 amp.-turns.

35. Determining Polarity of Electromagnets.—A simple method for determining the polarity of an electromagnet, if the direction of current is known, is to grasp the coil in the right hand

with the fingers pointing around the core in the same direction as the current flowing in the winding. With the hand in this position, the thumb will naturally point in the direction of the magnetic lines of force or along the core to the north pole.

The polarity of such an electromagnet may also be quickly determined by holding a compass near its poles. The north end of the needle will point to the south pole of the magnet, as already illustrated in Fig. 20.

36. Types of Coil Windings. Various methods of winding coils may be used, depending upon the result desired. The principal types of winding are the *inductive, the non-inductive, the accumulative compound*, and the *differential compound.*

The *inductive* winding consists of a simple winding, as shown in Fig. 32. This winding is used in winding electromagnets and induction coils. It is called *inductive* because a voltage will be induced in the winding during either the magnetizing or the demagnetizing of the coil.

The *non-inductive* type of winding is shown in Fig. 33. As may be seen, the wire is doubled back with as many turns around the core in one direction

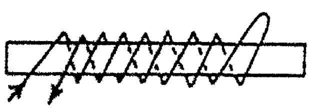


FIG. 33.—Non-inductive wound coil.

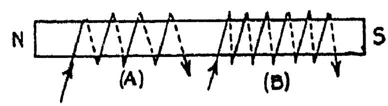


FIG. 34.—Accumulative wound coil.

as in the other. The magnetizing effect of the current in one wire will be neutralized by the opposite magnetizing effect of the current flowing in the other. Consequently, no magnetism will be produced in the core if current is sent through the winding. This type of winding is used when it is desired to wind a coil that is non-magnetic.

An *accumulative-compound-wound* coil is shown in Fig. 34. It consists of two windings wound on the same core. Each winding carries current

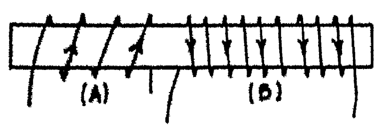


FIG. 35.—Differentially wound coil.

in the same direction around the core, producing magnetism in the same direction and making the magnetic effects *accumulative.*

A *differentially wound* coil is shown in Fig. 35. It is similar to the accumulative type, except that the current flows around the core in opposite directions in the two windings, thus causing the magnetic effect of one coil to oppose that of the other. If both windings should have the same number

of ampere-turns, the core will not show north and south polarity. If they are unequal, however, the winding producing the most ampere-turns will control the polarity of the core.

The last two types of windings are commonly used in the winding of cut-outs, regulators, and generator and motor field coils.

37. Electromagnetic Induction. It was pointed out in preceding paragraphs that a current flowing in a conductor produces a magnetic field which is set up around the conductor in a right-handed direction with respect to the flow of current, as shown in Fig. 27. It will also be found that, *if a magnetic field is set up around a conductor, an electric current will be caused to flow in the conductor* and that the same relation will exist between the direction of current flow and the magnetic field. This rela-

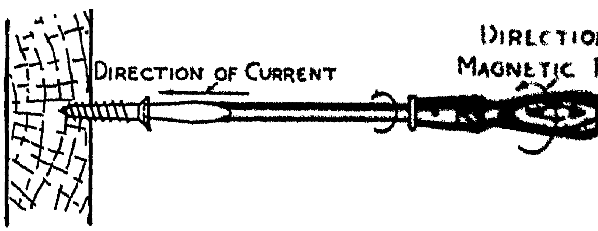


FIG. 36.—Relation between direction of current and magnetic field.

tion is shown very clearly in Fig. 36, in which the forward travel of the screw represents the direction of current, and the rotation of the screwdriver the direction of magnetism.

The process of generating a current in this manner is known as *induction,* and the current thus produced is called an *induced current.* If the current is generated by magnetism alternating in direction, the induced current will also be alternating in direction, with as many reversals per second through the wire as there are reversals of magnetism around it. Such a current is called *alternating current* and is usually abbreviated *A.C.*

A magnetic field may be set up around a wire in two ways: either by *cutting a magnetic field with a wire,* such as rotating an armature of a magneto or generator in a magnetic field, or by *cutting the wire or coil of wire with a rapidly moving magnetic field,* as in the inductor-type magneto and in the induction coil.

The method by which a magnetic field is set up around a conductor and the relative direction of the induced current are

illustrated by Fig. 37, in which N and S represent the north and south poles of a magnet and W a wire cutting through the magnetic field between N and S in a downward direction. The magnetic lines of force between N and S cause an attraction between the poles like that of many rubber bands under tension. It is evident that rubber bands, if intercepted by a moving wire, would be crowded ahead, as indicated in Fig. 37B.

In a similar way, it may be assumed that the magnetic lines of force will be distorted by the moving wire as shown in Fig.

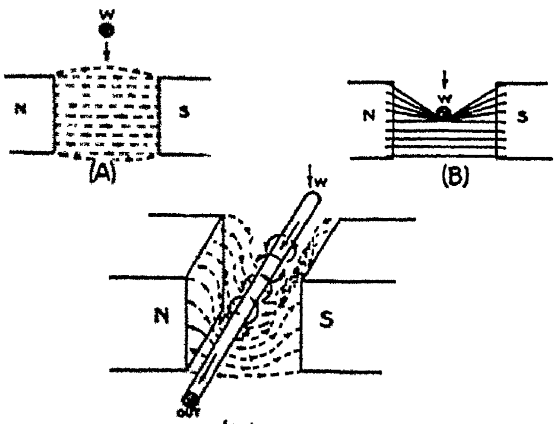


FIG. 37. Principle of electromagnetic induction.

37 C. From this figure it may be noted that the distorted lines of force crowding ahead of the moving conductor or wire create a field of greater intensity on one side of the conductor than on the other. This has the effect of setting up a magnetic whirl around the conductor in an anti-clockwise direction, as shown, thereby inducing a voltage and current in the conductor outward, as indicated by the arrow. This whirl of magnetic lines may be likened in direction to a whirlpool caused by water turning a sharp bend in a creek, as in Fig. 38, in which the water corresponds to the magnetic lines of force.

If, on the other hand, the wire is stationary and the magnetic lines are made to cut the wire, the effect will be the same. A current and voltage will be induced in the wire. In either case, the direction of the current set up in the wire will be dependent upon the direction of the magnetic lines between the poles and upon the

direction in which the wire cuts the magnetic lines of force. Furthermore, the voltage and current thus produced will be proportional in strength to the resistance of the wire, to the strength of the magnetic field, and to the speed at which the magnetic lines of force are cut.

The Right-hand Rule.—An easy method for determining the relation between the induced current, the direction of magnetism, and the motion

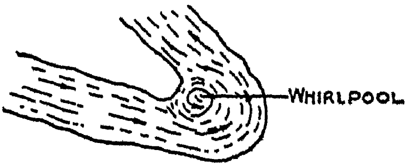


FIG. 38.—Water analogy of magnetic whirl around a conductor.

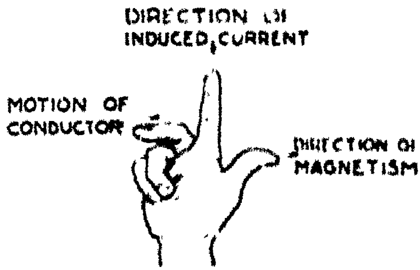


FIG. 39.—Right-hand three-finger rule for determining the direction of induced current.

of the wire through the magnetic field is to hold the thumb and first two fingers of the right hand at right angles, as shown in Fig. 39. If the thumb is made to point in the direction of the magnetic field, and the second finger in a direction corresponding to the relative motion of the conductor, the first finger will naturally point along the conductor in the direction of the induced current.

38. The Simple Alternating-current Generator.—If a single loop of wire is revolved in a magnetic field between a north (N)

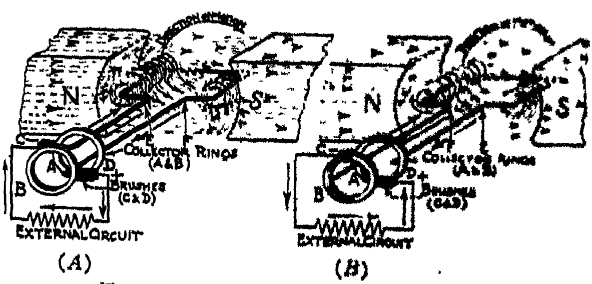


FIG. 40.—The simple A.C. generator.

pole and south (S) pole, as shown in Figs. 40*A* and *B*, an electrical pressure, termed *electromotive force*, will be induced in the two sides of the loop. The voltage and the current thus induced will be in a definite relation to the direction of the magnetism and

the direction of rotation of the wire loop. If the terminals of the loop are connected to two metal collector rings, such as A and B, upon which two metallic or carbon brushes rest, the induced electrical pressure will cause a current to flow through the external circuit connected across the brushes. If this loop is rotated in a clockwise direction, the sides of the loop E and F will cut the magnetic lines of force, first in one direction, Fig. 40A, and then in the reverse direction, as in Fig. 40B. This action will induce an alternating voltage in the loop which terminates at the brushes and will cause an alternating current to flow through the external circuit. When the loop is in a horizontal position, it cuts the greatest number of lines of force. When it is in a vertical position, no lines of force are cut and no voltage is induced. One complete revolution of the loop causes one complete reversal of the current.

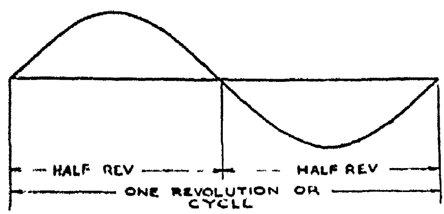


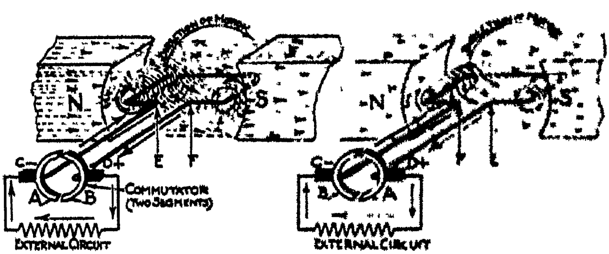
FIG. 41 Curve showing value of current during one revolution of simple A C. generator

The current value during one complete revolution or cycle of the loop may be represented graphically by the curve shown in Fig. 41, known as the *sine* curve. The highest point or peak above or below the horizontal line represents the highest voltage reached when the loop is in a horizontal position. After one-half revolution of the loop, the voltage is zero. It then reverses in direction. The reverse current is indicated by the curve below the horizontal line.

39. The Simple Direct-current Generator. The alternating current produced in a loop may be converted into direct current in the external circuit by replacing the two collector rings by a simple two-segment commutator as shown in Fig. 42. The two segments of the commutator are connected to the two ends of the loop, but are otherwise insulated from each other.

The only connections between the commutator segments are through the armature loops and through the brushes and the external circuit. The brushes remain stationary and make a rubbing contact, first with one segment and then with the other, as the commutator and the loop rotate together. With this

arrangement, as fast as the loop turns over and as fast as the induced voltage reverses in the loop, the segments change connection with the brushes and the current is made to flow, every half turn, through the external circuit in the same direction. The current thus obtained in the external circuit is direct current, and may be represented graphically as in Fig. 43. By comparing Figs. 41 and 43, it may be seen that the result has been to direct both impulses of current in the same direction.



(A) (B)

FIG. 42.—Simple D.C. generator.

If such a direct-current generator were constructed with an armature of a single winding of one or more turns, it would be inefficient and unsatisfactory, since the current would pulsate in value. To overcome this trouble, the armature core, which is in the form of a laminated-iron cylinder, is wound with many coils equally spaced around its circumference, each coil being connected to separate segments in the commutator. These coils are connected so that the current impulse of one coil overlaps the current impulse of the next, much the same as the overlapping of the power impulses in an eight- or a twelve-cylinder engine. The result is practically a continuous and steady flow of current.

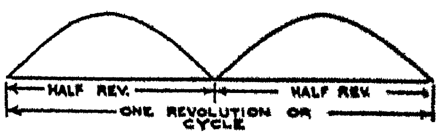


FIG. 43.—Curve showing value of current during one revolution of simple D.C. generator.

40. The Simple Direct-current Motor.—A direct-current motor is a dynamo which will run as a motor on direct current. Its construction is similar to the direct-current generator, although the operation is reversed. As a matter of fact, any automobile generator in good condition will run as a motor with the same

direction of armature rotation, as it must be driven to operate properly as a generator.

If a current is sent through a loop of wire, as shown in Fig. 44, the wire will rotate the same as the armature in a complete motor. Stated briefly the rotation of a loop is caused by repulsion between the magnetic field of the magnets and the magnetic field set up around the loop of wire by the current flowing through it.

A simple experiment from which may be readily determined the direction of this repulsion in relation to the direction of

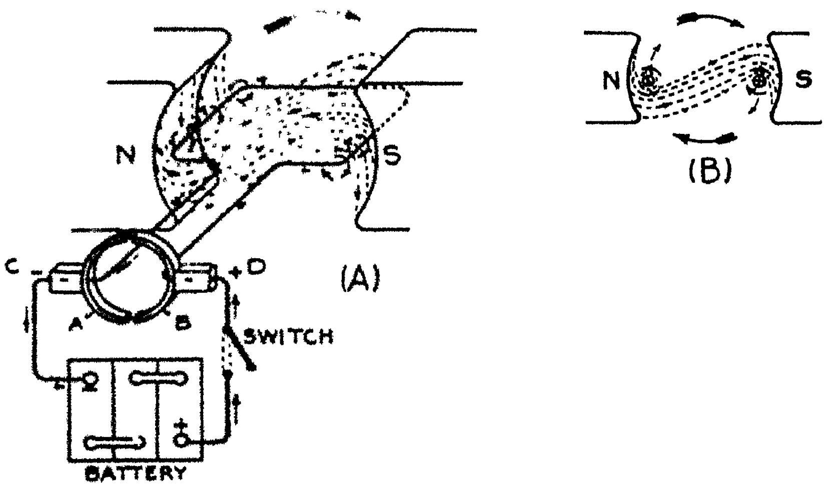


FIG. 44. Principles of the direct-current motor.

current and magnetism is shown in Fig. 45. If the magnet is placed so that the north (N) pole is above the wire W and current is sent through the loop of wire, in at E and out at F as shown, the wire will be repulsed to the position W_1. The repulsion is caused by all the magnetic lines of force tending to flow around the conductor in the same direction and the consequent distortion and crowding of the magnetic lines on one side of the conductor more than on the other. This results in a repulsion of the conductor as shown in Fig. 45B. On the other hand, if the magnet is reversed, thus reversing the magnetism, but the direction of current is unchanged, the magnetic lines of force will crowd to the other side of the conductor and it will be repelled in the opposite direction, as shown in Fig. 45C, and the wire will

be repulsed to the position W_2 Fig. 45A. The same action would result if the current were reversed instead of the magnetism. Thus, in Fig. 44A, on account of the current flowing in the two sides of the loop *A* and *B* in reverse directions, and the consequent field distortion as shown in Fig. 44B, *A* will be repulsed upward and *B* downward and the loop will rotate in a clockwise direction. The action is similar to the attracting and the repelling actions of magnets.

The cause of armature rotation may be further illustrated by suspending a bar magnet and bringing the opposite poles of two

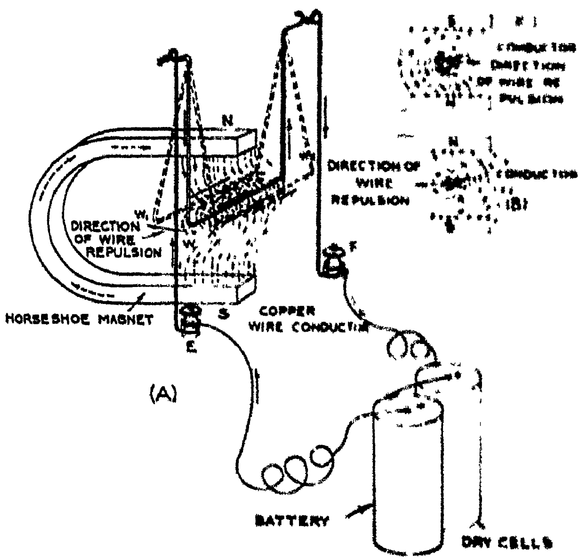


FIG. 45.—Experiment showing the relation between direction of magnetism, direction of current, and the direction of wire movement.

other magnets near it, as in Fig. 46. Since like poles of magnets repel each other the suspended magnet will revolve in the direction indicated. Another way of illustrating armature rotation is by the attraction method illustrated in Fig. 47. Since unlike poles attract each other, the south pole of the compass needle will rotate with the north pole of the magnet.

Figure 48 shows a cross-section of the loop illustrated in Fig. 44, but with the current reversed. It will be found that, with the direction of current reversed, the direction of rotation will also be reversed, provided the direction of field magnetism remains

unchanged. This may be explained as follows: If a current is sent in at A and out at B, the magnetic field which is set up around the wire will cause a crowding of the magnetic lines of force above A and below B. This will tend to produce a repelling action and the wire loop will revolve in a counter-clockwise direction as indicated.

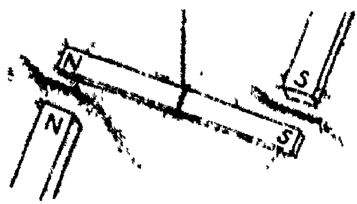


Fig. 16. Rotation due to magnetic repulsion.

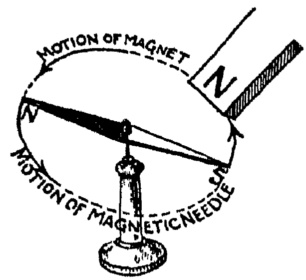


Fig. 17 Rotation due to magnetic attraction

The force with which the armature in a motor tends to revolve is proportional to the number of active armature coils, the strength of the magnetic field and the amount of current flowing through the armature winding. In practice, for example in the starting motor, the motor armature has many armature coils equally spaced around the entire circumference of the armature

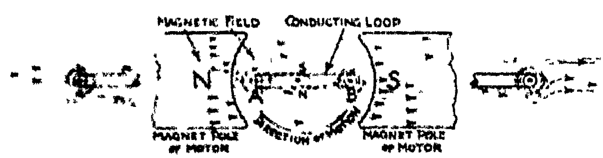


Fig. 18. Illustrating the cause of motor armature rotation.

core. Each coil carries current and, consequently, exerts a force to rotate the armature as it passes the pole pieces. The result is a comparatively high turning effect or *torque*, which, if applied through suitable gear reduction, would be sufficient to crank the engine.

41. Methods of Determining Electrical Polarity.—The following test methods will be found useful in determining the polarity of live wires:

Electrolyte Method.—With suitable resistance, such as an incandescent lamp, connected in the circuit to prevent excessive current from flowing, submerge the ends of two test leads, Fig. 49, about ½ to 1 in. apart in a glass of water in which a little common salt has been dissolved. The current in passing through the water will liberate gas (chiefly hydrogen) which will form in fine bubbles, particularly around the *negative* terminal. This test is also valuable in distinguishing between alternating and direct current, since alternating current will cause bubbles to collect equally around both terminals.

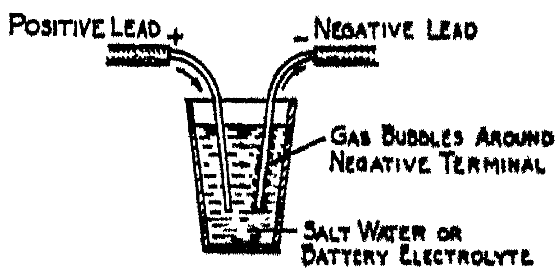


FIG. 49.—Electrolyte method of determining polarity of live wires.

Compass Method.—With the circuit completed through a suitable resistance, hold a compass (magnetic needle) above or below the wire carrying current and note the direction of needle deflection. The north end of the needle will point around the wire in the direction of magnetism, as in Fig. 28. The direction of current flow as well as the positive and negative terminals are then evident.

Voltmeter Method.—Connect the two test leads to the terminals of a voltmeter of the type which registers in one direction only (known as the magnetic-vane type). The needle of the instrument will register on the scale only when the positive and negative leads are connected to the terminals marked positive (+) and negative (−) on the voltmeter. If the connections are reversed, the needle will be deflected off the scale. Be sure that the range of the voltmeter is as high or higher than the voltage to be measured.

Potato Method.—Insert the points of the two test leads about 1 in. apart in the meat of a raw potato. A green spot will form around the positive and gas bubbles collect around the negative terminals, respectively.

SECTION III

IGNITION REQUIREMENTS OF AUTOMOTIVE ENGINES

42. The Internal-combustion Engine.—Any engine which operates through the burning of fuel inside the engine itself is termed an *internal-combustion engine*. Although the principle of the internal-combustion engine was first introduced as early as 1678, the first engine to attain any marked degree of commercial success was patented by J. J. E. Lenoir, in France, Jan. 1, 1860, and in the United States, Mar. 19, 1861. This engine was later improved by Nicholas A. Otto, a German, who, in 1876, produced an engine of the four-stroke-cycle principle, which is the basic principle still used in modern automotive engines.

43. The Gas-engine Cycle.—It was found by Otto that, in order to have an internal-combustion engine run continuously, a definite series of events, occurring in proper order, is necessary. These events are: (1) *intake* of the fuel charge (gas and air) into the engine cylinder, (2) confinement and *compression* of the fuel charge, (3) *ignition* and *combustion* of the fuel mixture to provide the driving power, and (4) *exhaust* or discharge of the burned gases from the cylinder preparatory to the next intake of fuel charge. In the Otto engine two revolutions of the crankshaft, or four strokes of the piston, are required to complete the four events, thus one piston stroke is required for each event. The engine is, therefore, said to operate on the *Otto cycle principle*. Today such an engine is commonly referred to as operating on the *four-stroke-cycle* or just the *four-cycle* principle.

It was also found that, by having certain events of the gas-engine cycle occur at the same time, all of them could be crowded into one revolution of the crankshaft or two strokes of the piston. Such an engine, in which all the events of the working cycle are completed in two strokes of the piston, is therefore called a *two-stroke-cycle* engine, and often referred to as a *two-cycle* engine.

The gas-engine cycle may be defined as a *series of events* (*intake, compression, expansion or power, and exhaust*) *which must occur*

in the operation of any internal-combustion engine in order that it may run continuously on its own power. The word *cycle*, as used in this connection, should not be misinterpreted to mean *circle* or *stroke*, as is often done by the general public.

44. Operation of the Four-stroke-cycle Engine. Figures 50, 51, 52, and 53 show sections of a typical automobile-type

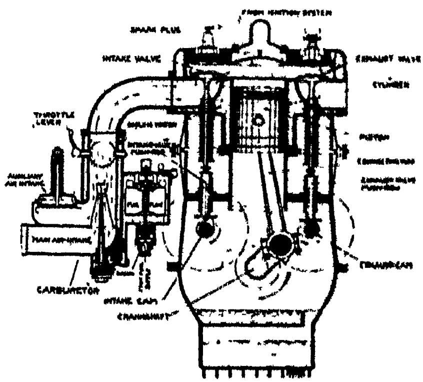


Fig. 50.—The intake stroke.

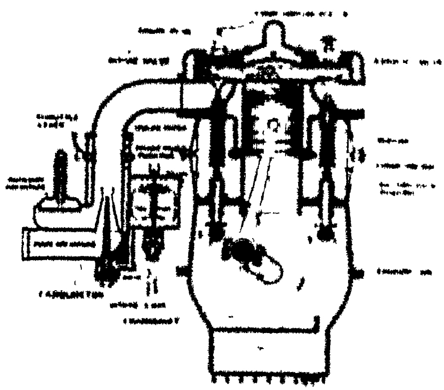


Fig. 51.—The compression stroke.

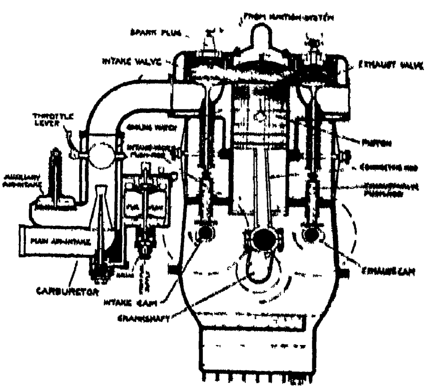


Fig. 52.—The power stroke.

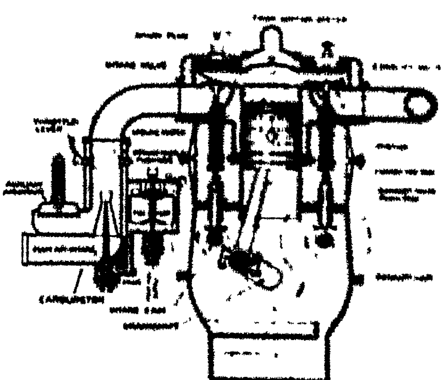


Fig. 53.—The exhaust stroke.

engine operating on the four-stroke cycle. These illustrations show the same engine at different events of the working cycle. The T-head type of cylinder construction is shown in preference to the L-head or the I-head construction merely because it is easier to show the operation of the various parts. Figure 54 illustrates the L-head and I-head types of construction.

As may be seen, the engine consists of six principal parts: (1) the *cylinder* which is stationary and in the top of which the explosion occurs, (2) the *piston* which operates up and down in the cylinder and receives the force of the explosion, (3) the *connecting rod* which transmits the force of the explosion from the piston to the crankshaft, (4) the *crankshaft* which rotates and receives the force of the explosion as transmitted by the piston and connecting rod, (5) the *carburetor* which vaporizes the liquid fuel and mixes it with the proper amount of air for delivery to the cylinder, and (6) the *valve mechanism* which admits and discharges the gases at the proper time to permit of continuous operation.

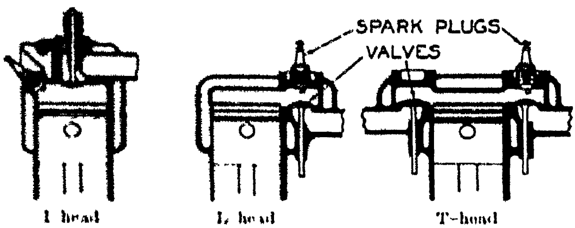


Fig. 54.—Location of spark plugs and valves in various types of cylinder heads

The events which occur in the operation of the internal-combustion engine are accompanied by the opening and the closing of the intake and exhaust ports or valves. The periods during which these valves open and close in relation to the position of the crankshaft are shown in Fig. 55. This diagram represents the two revolutions of a four-cycle engine and indicates the crank positions when the different events begin and end. The diagram is drawn for a vertical engine with the crank turning clockwise, corresponding to the direction of rotation of an ordinary automobile engine as viewed by a person standing in front of the car and looking toward the engine.

In studying this diagram, it will be well to refer occasionally to the four views shown in Figs. 50, 51, 52, and 53. It should be assumed that the piston is at the top dead-center position, ready to start down on the intake or suction stroke, as shown in Fig. 50. The intake valve opens when the crank has passed the top dead-center position by approximately 10 deg., as indicated by point *A* on the diagram, Fig. 55. The exhaust valve is closed at this time and the piston moves downward (the intake valve remaining open), drawing in a fresh charge of gas. The intake valve remains open until

the crank has passed the bottom dead-center position by approximately 30 to 40 deg., as indicated by point B on the diagram. The valve now closes and the piston moves upward, compressing the fuel charge, Fig. 51. The power utilized in compressing this charge is furnished by the flywheel. At the point C, when the piston is approaching the top dead center, ignition occurs, setting fire to the fuel charge.

The exact time ahead of top dead center at which ignition should occur depends upon several factors, such as the speed of the engine and the type of cylinder head used. The point of ignition should occur sufficiently far ahead of the upper dead-center position so that, by the time the crank has reached its top dead-center position D, the maximum force of explosion available to drive the piston downward on its power stroke will be attained.

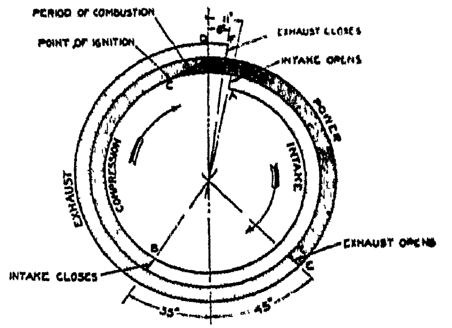


FIG. 55.—Valve operating diagram for typical four-cycle automobile engine.

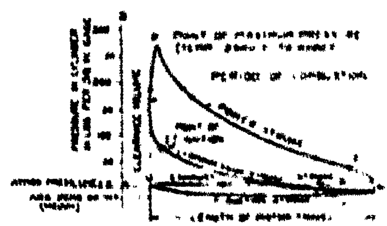


FIG. 56.—Gas pressure diagram for typical four-cycle engine.

At this time, both valves are closed and the piston is driven downward by the force of the explosion, permitting the gas to expand and the pressure to drop.

When the crank has reached position E, which is ordinarily from 30 to 50 deg. before lower dead center, the exhaust valve opens, permitting the gases to be exhausted. The exhaust valve remains open while the crank moves from E around to F, a point at which it closes. This point is usually at upper dead-center position or a few degrees past. Normally, it is about 5 to 8 deg. past, which is just a few degrees before the intake valve opens again for the next fuel charge. The engine has now passed through one complete engine cycle. The variation of gas pressure in the cylinder during the cycle is illustrated in Fig. 56, the curve representing the pressures at different positions of the piston.

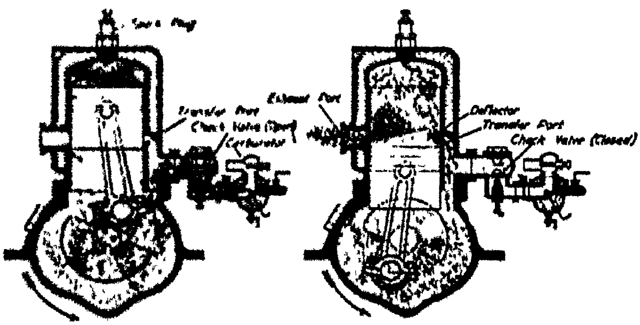
It will be noted that the exhaust valve opens approximately 45 deg. before the piston has completed its power stroke. The purpose of this is to permit the pressure inside of the cylinder to be reduced (as nearly as possible) to the air pressure outside the engine (or atmospheric pressure) by the end of the power stroke in order to keep the back pressure on the piston during the following exhaust stroke as low as possible. At the end of the exhaust stroke, the exhaust valve should remain open for a brief period while the

crank is passing the center, so that any pressure remaining in the cylinder may have time to reduce to atmospheric pressure.

The inlet valve does not usually open before the exhaust closes, although a few engines on the market operate contrary to this rule. The reason for delaying the opening of the inlet valve is to eliminate the possibility of the engine backfiring through the intake valve and manifold. It will also be seen that the intake valve remains open for a considerable time (about one-fifth of a revolution of the crankshaft) after the bottom dead center has been passed. The purpose of this arrangement is to permit the maximum fuel charge to be drawn into the cylinder, for at the end of the suction stroke there is still a slight vacuum in the cylinder. The inlet valve usually closes about 35 deg. late, although this angle may vary, depending upon the speed of the engine, the design of the intake manifold, and the valve arrangement.

In most automobile-type engines, markings, which indicate the points of valve opening and closing, are given on the flywheel. These will be found valuable in valve setting and ignition timing.

45. Operation of the Two-stroke-cycle Engine.—In the two-cycle engine, a typical example of which is shown in Figs. 57*A* and *B*, the cycle or series of events, namely, *intake*, *compression*,



(*A*) (*B*)

FIG. 57. Typical two-cycle engine. (*A*) Firing position. (*B*) Exhaust and intake position.

expansion, and ***exhaust***, are completed in two strokes of the piston or one revolution of the crankshaft. The engine, instead of having valves, has exhaust and intake ports cast in the sides of the cylinders. These ports are opened and closed automatically by the piston as it moves up and down within the cylinder. The fuel charge, instead of entering the cylinder directly from the carburetor, as in the four-stroke-cycle engine, is drawn first into the crankcase. A check valve is used between the carburetor and engine.

During the power stroke of the piston, the fuel for the succeeding charge is partially compressed in the engine crankcase. When the piston is nearing the end of its power stroke, it uncovers the exhaust port and the burned gases escape to the atmosphere. Shortly after the exhaust port opens, the intake port opens on the opposite side of the cylinder and the partially compressed fuel charge in the crankcase rushes past the piston, through the ports, and into the cylinder space above, as indicated in Fig. 57*B*. Two operations or events, namely, exhaust and intake, occur at the same time. Likewise, slight compression below the piston, and combustion or power above it, take place at the same time. On the return stroke of the piston to its upper position, the intake and the exhaust ports are closed, and the fuel charge is compressed for the following power stroke.

As just explained, intake and exhaust occur at the same time. This means that the fresh fuel charge is mixed to a certain extent with the burned gases of the previous explosion. To prevent as much as possible, the mixing of the intake and the exhaust gases, a lip or *deflector* is cast on the top of the piston. This lip directs the intake gases upward, yet allows the exhaust gases free chance to escape.

At the present time, the two-cycle engine is not used in the automobile, but is used considerably in motor boats and to some extent in motor cycles and farm-lighting plants. The two-cycle engine has the advantage over the four-cycle engine in that it will run in either direction, not requiring reverse gearing for reversing the direction of the boat or vehicle in which it is installed. It also requires a smaller flywheel, proportionately, since each downward stroke is a power stroke. Offsetting these advantages, however, must be considered poor fuel economy and difficulties in cooling and lubrication.

In comparing the ignition requirements of four-cycle and two-cycle engines, it should be remembered that the four-cycle engine requires one ignition spark for each four strokes of the piston, or two revolutions of the crankshaft; while in the two-cycle engine, an ignition spark must be provided every two strokes of the piston, or one spark for each revolution of the crankshaft.

46. Principles of Carburetion.—The function of the carburetor is to atomize, or vaporize, the liquid fuel (usually gasoline or kerosene) and furnish the proper mixture of air and fuel vapor to each cylinder under all conditions of temperature, speed, load, power, and varying atmospheric conditions. Gasoline is the fuel universally used in variable-speed automotive engines, although kerosene has been used with good success in engines having fairly constant speed, such as tractors and stationary engines.

As may be seen from Fig. 30, the supply of gasoline furnished to the carburetor is controlled by a fuel float, which maintains a constant level of gasoline, slightly below the top of the fuel nozzle. As the piston moves downward on its suction stroke, the partial vacuum, or, as it is commonly called, the *suction pressure*, draws air through the air-intake tube and past the fuel nozzle of the carburetor. This suction also draws the liquid gasoline through the fuel nozzle, from which it escapes in the form of a fine spray. The atomized gasoline in passing through the manifold is heated and mixed with the air. This tends to vaporize more of the atomized fuel, so that it is a highly explosive gas when compressed and ignited within the cylinders.

47. Effect of Carburetion upon Ignition.—The proportion of fuel and air in the mixture has an important effect upon ignition and combustion. The purpose of the air is to supply the oxygen necessary for combustion. If too little air be furnished, there will not be enough oxygen to burn both the carbon and the hydrogen contained in the fuel; consequently, a part of the fuel (carbon) will be wasted. This will be indicated by black smoke coming from the exhaust. The mixture, under these conditions, is said to be *too rich*. On the other hand, if too much air is supplied for the amount of fuel present, the mixture is said to be *too lean*, resulting in a weak explosion and backfiring through the carburetor at low speeds. Furthermore, a mixture that is too rich in fuel is a slow-burning mixture, and if too rich—less than seven parts of air to one of gasoline by weight—it may not burn at all. On the other hand, if the mixture is so lean that there are more than twenty parts of air to one of gasoline by weight, it may also misfire.

On an average, a proportion of fourteen to fifteen parts of air by weight to one part of gasoline vapor by weight gives the best results, but the exact proportions will depend somewhat upon the quality of fuel used and the extent of vaporization. When the proper proportions of air and vapor are present in the fuel charge, it will burn with a blue flame similar to the flame in a properly adjusted gas range. Too much air causes a white flame, too much fuel an orange-colored flame.

48. The Progress of Combustion.—In order to obtain a clear understanding of what takes place in the cylinder during combustion, the entire action may be imagined to be slowed down. First the combustion chamber, full of compressed gas, should be

pictured with an electric spark passing between the spark-plug points, as in Fig. 52. Because of the heat of the spark, a flame will be started in the layer of gas in immediate contact with the spark-plug electrodes. This flame sets fire to the surrounding gas—in fact, the flame spreads in all directions from the spark plug, somewhat as ripples spread when a stone is thrown into a pool of water. But the flame—unlike the ripples—proceeds at a constantly increasing rate of speed and is accompanied by a rapidly rising temperature and pressure within the combustion chamber. Finally, the entire fuel charge is ignited. The time required for the flame to travel from the point of ignition to the far corners of the combustion chamber is known as the *period of flame propagation*.

Thus, combustion in a gas engine is not instantaneous any more than the combustion of a brush pile or straw stack is instantaneous when fire is started only at one point. It is, therefore, technically incorrect to refer to the combustion as an explosion. There could only be an explosion if the entire combustible mixture was raised to its kindling temperature and all ignited at the same instant.

It is evident from the foregoing that the shape of the combustion chamber has considerable influence on the time required for flame propagation and the consequent power and fuel economy of the engine. In this respect the I-head type of engine has the advantage over the L- and T-head types, since it has the most compact combustion space and, consequently, the shortest distance for the flame to travel.

The location of the spark plug is also important. If it is located near the center of the combustion chamber, the flame will spread through the whole mass more quickly than if ignition occurs at one corner of the chamber. To shorten the time of combustion, T-head engines are sometimes provided with two spark plugs located at distant points in the cylinder head—usually one plug over each valve—and arranged so that a spark will occur at the same instant in both plugs.

49. Factors Governing Speed of Combustion.—Fundamentally, the rate of flame propagation is a question of the intensity of the heat generated by the combustion as the flame spreads from one layer of gas mixture to another. Furthermore, the amount of heat developed depends upon the quality of the fuel mixture, its temperature, and pressure. The speed of combustion is also dependent upon the compression pressure, since in a highly compressed mixture the heat developed in each unit of volume is more intense.

50. Principles of Ignition Timing Spark Advance.—The time of the ignition spark should be such that the maximum explosive pressure is obtained when the piston is on top dead-center position ready to start down on its power stroke. This means that, because of the time required for flame propagation, ignition must occur before the crank reaches dead center. The amount of this *spark advance* depends upon several factors, such as the speed of the engine, the shape of the combustion chamber, the location of the spark plug, and the quality of the fuel charge.

51. Spark Advance and Retard. The above considerations require that the time at which the spark occurs should be made variable. This is usually done by shifting the device for timing the ignition spark (either a timer or breaker) relative to the engine crankshaft, so that the sparks will occur in the cylinders earlier or later according to the direction in which the device is shifted. The usual procedure is to time the spark so that, at low speed, ignition will occur when the piston is approximately at the upper dead-center position, with the spark-control device completely retarded. The operator should advance the spark as the engine speed is increased, to obtain the best engine performance. Usually, a spark advance range of 30 to 40 deg. is provided.

If the spark should be advanced too far, there will be a decided knock in the cylinders. On the other hand, if the spark is retarded too far, the engine will tend to overheat, causing boiling of the cooling water, and a decided loss of power. The best results are usually obtained with the ignition advanced as far as possible without causing the engine to knock.

52. The Multiple-cylinder Engine.—As previously pointed out, the single-cylinder, four-cycle engine gives one power impulse during two revolutions of the crankshaft. This means that there is a power stroke every fourth stroke of the piston, the flywheel being depended upon to keep the engine running during the other three strokes. The main purpose of the multiple-cylinder engine is to provide power impulses at frequent intervals in order to have an engine that will run quietly and at the same time deliver a large amount of power.

As the number of cylinders increase, the power impulses increase in frequency; the average power is greater, and, for engines having more than four cylinders, there is no period in

the revolution of the crankshaft during which some one cylinder is not delivering power.

This means that in a six-, eight-, or twelve-cylinder engine of the usual type there is no time during which the momentum of the engine flywheel must supply all the driving power as is the case in a single- or a two-cylinder engine. The multiple cylinder engine, therefore, tends to furnish a continuous supply of driving power with a minimum amount of variation or vibration. The increase in the number of cylinders used tends to reduce the size of each cylinder. This, combined with the steady operation of the engine, makes it a remarkably quiet and smooth running power-plant unit.

53. The Two-cylinder Engine Opposed Type. A two-cylinder engine in which both cylinders lie horizontally with

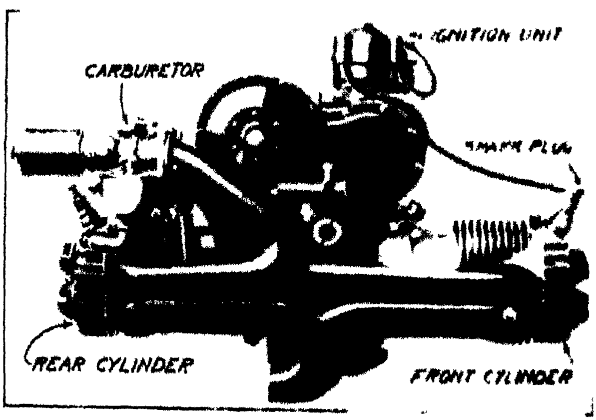


FIG. 58.—Two-cylinder opposed type motorcycle engine. (Harley Davidson.)

heads in opposite directions, as shown in Fig. 58, is known as a *two-cylinder opposed* engine. Such an engine is used commonly for tractors, light delivery trucks, motor-driven farm machinery, and motor cycles. The arrangement of the crankshaft and pistons is shown in Fig. 59. It will be noted that both pistons operate together, that is, both are on the outward end and, likewise, on the inward end of their strokes at the same time.

In a two-cylinder engine of the four-cycle type, both cylinders must fire in two revolutions or four strokes. In order, therefore, that the power impulses may occur at equal intervals, one cylin-

der should fire during one revolution and the other during the next, namely, 360 deg. or one revolution apart. With this in mind, assume that No. 1 piston is nearing its upper or head-end, dead-center position, just completing its compression stroke prior to ignition. The piston in cylinder No. 2 must necessarily be rising on its exhaust stroke.

Relation of Events.—The events which occur simultaneously in the two cylinders during any one of the four strokes may be readily determined from the table shown in Fig. 60. From this table, it may be seen that, when No. 1 cylinder is completing its compression stroke preparatory for ignition, No. 2 cylinder is completing its exhaust stroke prior to intake. Likewise, when No. 2 cylinder is completing its compression stroke ready for igni-

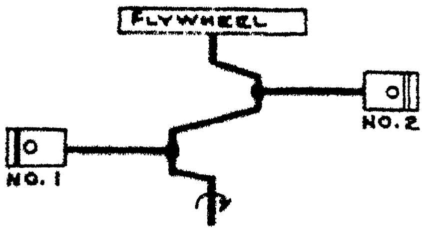


FIG. 59.—Diagram of typical two-cylinder opposed type engine.

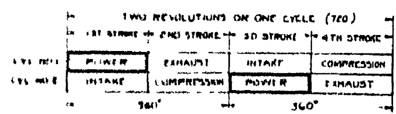


FIG. 60.—Table showing relation of events in two-cylinder opposed type four-cycle engine.

tion, No. 1 cylinder is completing its exhaust stroke prior to intake. Thus, with an engine of this type, two ignition sparks are required of the ignition apparatus during two revolutions of the engine. One spark is delivered to one cylinder during the first revolution, and the other spark to the other cylinder during the next revolution.

Some engines of this type are designed so that sparks occur at both spark plugs at the same instant. This arrangement eliminates the use of a high-tension distributor but is possible only under proper conditions, namely, that the time of the ignition spark occurs on or before the piston has passed its head-end, dead-center position.

As previously explained, the intake valve does not open until a few degrees (a slight turn) after the exhaust valve closes, or approximately 10 to 12 deg. past upper dead-center position. This means that when No. 1 cylinder is filled with combustible gas under compression and is ready for ignition, No. 2 cylinder still contains some burned exhaust gases from the previous explosion at approximately atmospheric pressure. If, then, the ignition spark is caused to occur at both spark plugs at the same instant, the spark in No. 1 cylinder will cause an explosion, while the spark in No. 2 may be considered a dead spark, inasmuch as it is in contact with non-combustible exhaust gases. As will be shown later, sparks can be made to occur in the two plugs at the same instant by connecting the two spark

plugs in series. One end of the secondary or high-tension wiring of the induction coil is connected to one plug, while the other end of this wiring is connected to the other plug.

Caution!—Care should be taken, in operating an engine of this type, against retarding the spark too far past dead center, since, if the spark should occur after the intake valve opens in the other cylinder, the supposedly *dead* spark may set fire to the incoming charge, causing a backfire through the intake manifold and carburetor.

54. The Two-cylinder Engine Side-by-side Type. The two-cylinder engine in which both cylinders are placed side by side is another typical form of engine used for light tractor and truck service. The relative positions of the pistons and cranks are shown in Fig. 61.

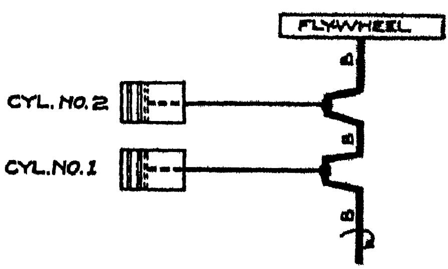


FIG. 61.—Crankshaft arrangement for two-cylinder side-by-side type engine.

Inasmuch as both pistons operate together, that is, both being at their head-end and crank-end, dead-center positions at the same time, the interval between explosions is 360 deg. The order of events, therefore, will be the same as for the opposed engine in Fig. 60. This being the case, when No. 1 cylinder is ready for ignition and its power stroke, No. 2 cylinder is completing the exhaust stroke preparatory for its intake stroke. Furthermore, two-spark ignition can be used, and the instructions given for the opposed type engine will also apply to this type of engine.

55. The Two-cylinder Engine—V-type. The two-cylinder engine, in which the cylinders are set at an angle, is called a *V-type engine.* Engines of this type are in common use on motor cycles.

The usual angles between cylinders for this type of engine are 42, 45, and 50 deg., the most common angle being 45 deg. Figure 62 represents the arrangement of the crank, connecting rods, and pistons for an engine with the cylinders at an angle of 45 deg. Both connecting rods are designed to operate on the same crank.

As in the engine of the two-cylinder opposed type, both cylinders must fire in two revolutions of the crankshaft, one during one revolution and the other during the next revolution. The interval between explosions, however, will not be equal, due to the angularity (V-position) of the cylinders. Assuming that the crank in Fig. 62 is rotating in a right-hand direction with the piston in No. 1 (rear) cylinder on the upper end of the stroke ready for ignition, the other piston must be going up on either its compression or its exhaust stroke. But, since the interval between explo-

sions should be as nearly equal as possible, when No. 1 cylinder is ready for ignition, the piston in No. 2 cylinder must be going up on its exhaust stroke so as to fire during the next revolution.

This being the case, No. 2 cylinder will not fire until the crankshaft has turned through one complete revolution plus the angle between cylinders (which in this case is 45 deg.), or a total angle of 360, plus 45, or 405 deg. In

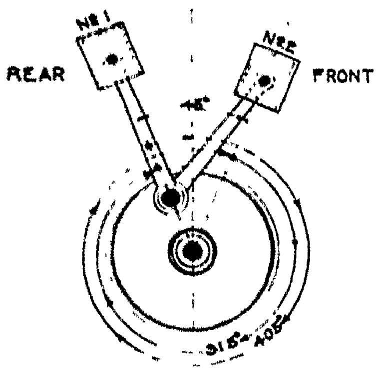


Fig. 62.—Arrangement of connecting rods and crank for two-cylinder 45 deg., V-type engine.

the interval between the time No. 2 cylinder fires and No. 1 cylinder fires, there must be one complete revolution minus the angle between cylinders, or 360 minus 45, or 315 deg. These two intervals added, of course, equal two revolutions, or 720 deg. The relation of events in both cylinders can be readily understood by studying Fig. 63, which is shown for a 45-deg. type engine.

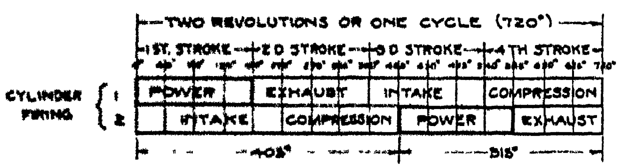


Fig. 63.—Relation of events in 45 deg., V-type engine.

Likewise, in a similar V-type engine of the 42-deg. type, the interval between explosions will be 102 and 318 deg. respectively, while in the engine of the 50-deg. type, the angles passed through by the crank will be 110 and 310 deg. respectively.

56. The Four-cylinder Engine.—The general construction of a typical four-cylinder, four-cycle engine is shown in Fig. 64. In this type of engine, four explosions must occur in two revolutions of the crankshaft or there must be two explosions per revolution. This means that the explosions should occur at equal

intervals of 180 deg. A typical arrangement of the crankshaft is shown in Fig. 65. In this view, it will be readily seen that pistons Nos. 1 and 4, and Nos. 2 and 3 operate together. (The cylinders are numbered back from the front of the car.)

With such a crankshaft, it is evident that more than one firing order may be obtained. When viewed from the front end of the engine with the crank rotating clockwise (as it does in all auto-

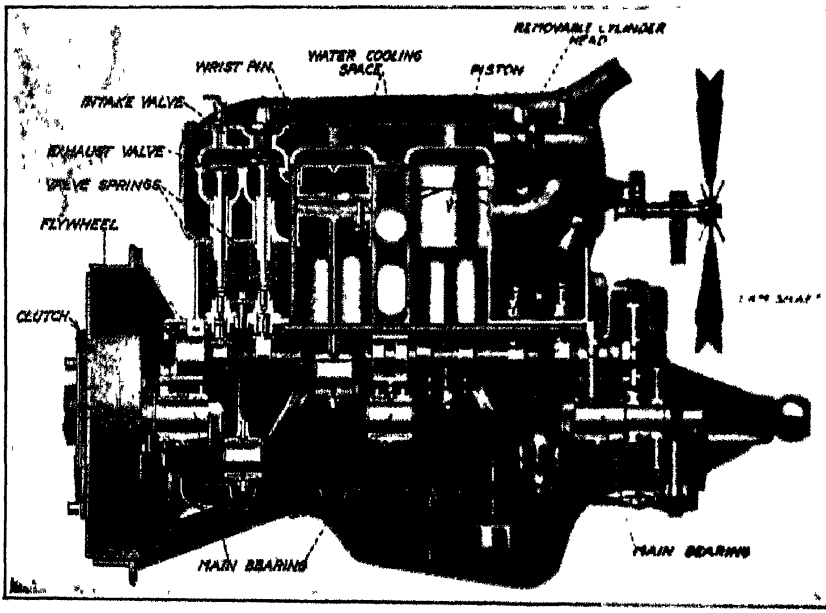


Fig. 64.—Sectional view of typical four-cylinder, four-cycle automobile engine (*Dodge*.)

mobile engines), with No. 1 cylinder on top center ready for ignition, the piston of the next cylinder to fire will be starting up on its compression stroke. This may be either piston No. 2 or piston No. 3. If No. 2 cylinder is the next one to fire, it must necessarily be followed by No. 4, then No. 3, making a firing order of 1-2-4-3. This is the firing order used by the Ford engine and many others. In case, however, the explosion in No. 1 cylinder is followed by No. 3, then No. 3 must be followed by No. 4, then by No. 2, giving a firing order of 1-3-4-2. Examples of this firing order will be found in the Dodge, Buick, Maxwell, and many other engines.

Relation of Events.—Convenient charts showing the relation of events in the different cylinders of a four-cylinder engine with firing orders of either 1-2-4-3 or 1-3-4-2 are shown in Figs. 66 and 67 respectively. From these tables, it may be seen that, regardless of the firing order, the

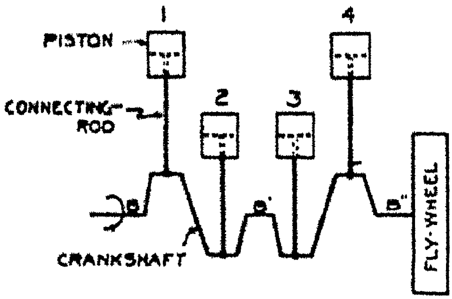


FIG. 65.—Arrangement of cranks in typical four-cylinder engine.

events which occur simultaneously in cylinders Nos. 1 and 4 and Nos. 2 and 3 are the same. That is, when one cylinder is ready for ignition, or its power stroke, the other, working with it, is completing its exhaust stroke preparatory for intake.

	TWO REVOLUTIONS OR ONE CYCLE (720°)			
	1ST STROKE	2D STROKE	3D STROKE	4TH STROKE
CYLINDER FIRING 1	POWER	EXHAUST	INTAKE	COMPRESSION
2	COMP	POWER	EX	INT
4	INT	COMP	POWER	EX
3	EX	INT	COMP	POWER

FIG. 66.—Relation of events in four-cylinder engine firing 1-2-4-3.

This condition makes it possible to employ on a four-cylinder engine a two-spark ignition system similar to that mentioned in connection with the two-cylinder opposed or side-by-side type engine, for in reality the four-cylinder engine is a combination of two two-cylinder engines. The cylin-

	TWO REVOLUTIONS OR ONE CYCLE (720°)			
	1ST STROKE	2D STROKE	3D STROKE	4TH STROKE
CYLINDER FIRING 1	POWER	EXHAUST	INTAKE	COMPRESSION
3	COMP	POWER	EX	INT
4	INT	COMP	POWER	EX.
2	EX	INT	COMP	POWER

FIG. 67.—Relation of events in four-cylinder engine firing 1-3-4-2.

ders in which sparks could occur simultaneously are Nos. 1 and 4 and Nos. 2 and 3 respectively.

After the engine is once built and the camshaft is made according to a certain firing order, the firing order cannot be changed. In choosing the firing order for a multiple-cylinder engine, it is of considerable advantage

to have the explosions skip around on the crankshaft as much as possible that is, two or more cylinders side by side should not fire in succession if it can possibly be avoided. The purpose of this is to aid in the cooling and lubrication of the engine. At the same time the crankshaft is relieved of some of the vibrational strain.

Comparison of Firing Orders.—In the firing orders of four-cylinder engines it will be found that there is really no difference in the distribution of the explosions, since the firing order 1-3-4-2 is merely the reverse of 1-2-4-3

It will be seen that the ignition equipment used on a four-cylinder engine must supply one ignition spark to each cylinder during two revolutions of the crankshaft at intervals of 180 deg., as already shown in Figs. 66 and 67

57. Six-cylinder Engines.—In six-cylinder automobile engines two types of crankshafts may be used as shown in Fig. 68, namely, that in which cranks Nos. 1 and 6 are followed by Nos.

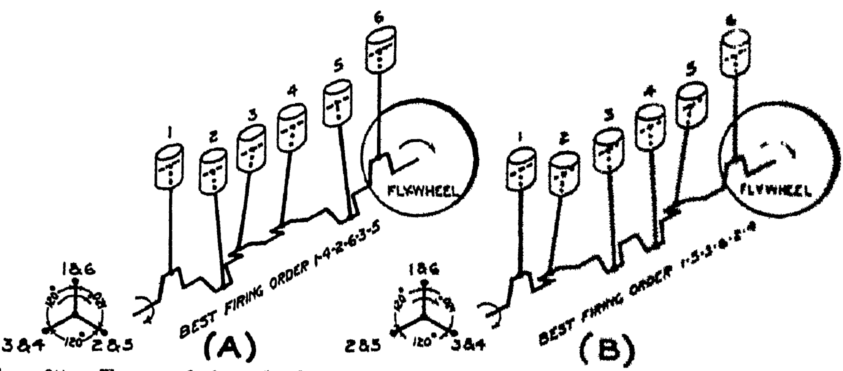


FIG. 68.—Types of six-cylinder crankshafts. (*A*) Left type crank firing 1-4-2-6-3-5. (*B*) Right type crank firing 1-5-3-6-2-4.

3 and 4, as shown in Fig. 68*A* and that in which cranks Nos. 1 and 6 are followed by Nos. 2 and 5, as shown in Fig. 68*B*. Thus, the firing order is controlled by the type of crankshaft used.

Inasmuch as all six cylinders must fire in two complete revolutions of the crankshaft, or 720 deg., the interval between explosions should be 720 divided by 6, or 120 deg. For this reason the cranks are 120 deg. apart, that is, cranks Nos. 1 and 6, 2 and 5, and 3 and 4 are in the same relative positions. The overlapping of the power impulses and other events is conveniently shown in the table of Fig. 69.

In the case of the crankshaft arranged as in Fig. 68*A*, when No. 1 cylinder is starting on its power stroke the piston of the next cylinder to fire must be part way up on its compression

stroke. This may be either piston No. 3 or 4. If No. 1 is followed by No. 4, No. 4 must be followed by either No. 2 or 5. Thus, if No. 4 is followed by No. 2, then No. 2 must be followed by No. 6, and No. 6 by Nos. 3 and 5 in order, giving a firing order of 1-4-2-6-3-5.

In looking at the front end view of this crankshaft, shown to the left, Fig. 68A, it will be seen that the various firing orders may be determined by choosing different combinations of numbers beginning with No. 1 and proceeding around the cranks in a backward or left-hand direction. It will be found that the same crankshaft could also fire 1-3-2-6-4-5, 1-3-5-6-4-2, and 1-4-5-6-3-2. The first firing order, 1-4-2-6-3-5, however, gives the best distribution of the explosions, consequently, is considered the best firing order for this type of crankshaft.

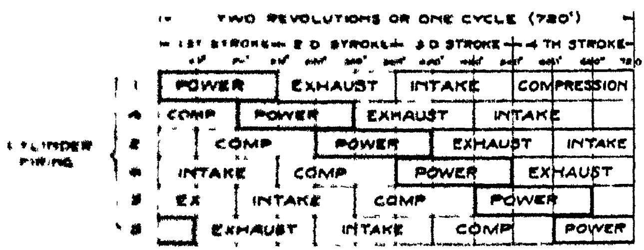


Fig. 69.—Relation of events in a six-cylinder engine firing 1-4-2-6-3-5

In like manner, the best firing order for the other type of six-cylinder crankshaft shown in Fig. 68B is 1-5-3-6-2-4. Upon comparing the two crankshafts, it will be found that in Fig. 68B the flywheel is mounted on the opposite end of the crankshaft from that shown in Fig. 68A. Otherwise the crankshafts are practically the same.

58. Methods of Determining the Firing Order of a Multiple-cylinder Engine. Several methods may be used to determine the firing order of any multiple-cylinder engine, in case it is not known to the mechanic or electrician.

Compression Method.—The most widely used method of determining the firing order is to open the petcocks, or remove the spark plugs, and turn the engine over slowly by hand, noting the order of compression. The use of this method is possible since each piston must come up on its compression stroke before ignition occurs. When the fingers are placed over the petcocks or the spark-plug openings the compression stroke of the piston will be indicated by a strong rush of gas or air outward through the openings.

Thus in a four-cylinder engine, if No. 1 cylinder is followed by No. 2, then the firing order must be 1-2-4-3. On the other hand, if No. 1 cylinder is followed by No. 3, then the firing order must be 1-3-4-2. Furthermore, in a six-cylinder engine, if No. 1 is followed by No. 5 and No. 5 by No. 3, the firing order must be 1-5-3-6-2-4. Likewise, if No. 1 is followed by No. 4, and No. 4 by No. 2, then the firing order must be 1-4-2-6-3-5.

Valve Method.—Another common method of determining firing orders is to watch the operation of either the intake or the exhaust valves. This method is usually more conveniently followed on engines with overhead valves, or with the cylinder head removed. First, it must be determined which are the intake and the exhaust valves. Their order of operation as to opening or closing should then be noted. It is, of course, evident that either set of valves will open or close in accordance with the firing order.

In a four-cylinder engine, it will be found that the time of closure of the exhaust valve in No. 4 cylinder is practically at the same instant at which ignition occurs in No. 1 cylinder. Likewise, in the six-cylinder engine, the point of exhaust valve closure in No. 6 cylinder is practically the same time at which ignition should occur in No. 1 cylinder, assuming in both instances that the spark is retarded so as to occur when the piston is at approximately dead center position.

In most instances, it will be found that the engine flywheel is marked with a punch mark or straight line to indicate when Nos. 1 and 4 or Nos. 1 and 6 cylinders are on upper dead center position. The flywheel usually also shows marks to indicate the time at which the intake and the exhaust valves should open and close. These markings will be found of great help to the electrician and mechanic in ignition timing.

59. Eight-cylinder Engines.—Several types of eight-cylinder engines have been introduced on the market. Each has its own peculiar ignition requirements. The different types include:

1. The eight-cylinder, 90-deg., V-type engine with all cranks in the same plane.
2. The eight-cylinder, 60-deg., V-type engine with all cranks in the same plane.
3. The eight-cylinder, 90 deg., V-type engine with the cranks in two planes.
4. The eight-cylinder engine with all cylinders in a straight row.

The ignition requirements of each type will be discussed in the order given.

60. The Eight-cylinder, 90-deg., V-type Engine with Cranks in the Same Plane.—A typical example of the 90-deg., V-type construction is found in all models of the Cadillac Eight prior to the 1924 model, type V-63. Figure 70 shows a cross-sectional

view of the engine and Fig. 71 a skeleton diagram showing the crankshaft and the relative positions of the various connecting rods and pistons when No. 1 in the right block is on top dead-center position.

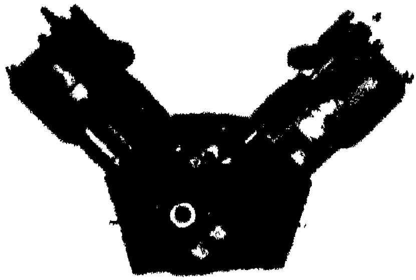


Fig. 70.—Sectional view of Cadillac eight-cylinder engine.

In reality, this engine may be considered as a combination of two four-cylinder engines mounted at an angle of 90 deg. and operating through a common crankshaft of the four-cylinder type.

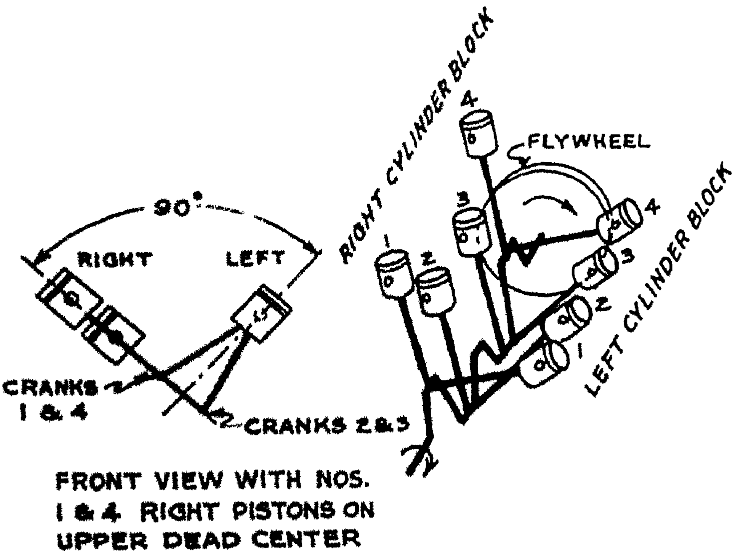


Fig. 71.—Arrangement of cranks, connecting rods, and pistons for eight-cylinder, 90 deg., V-type engine.

Two connecting rods operate on each crank. One common type of connecting-rod arrangement is shown in Fig. 72. This shows the fork or yoke type, in which one connecting-rod end is

forked, allowing the other one to operate inside of it on the same bearing. In another type of construction, the cranks operate side by side. This means that the cylinder blocks are slightly staggered to allow for the offset of the cylinders.

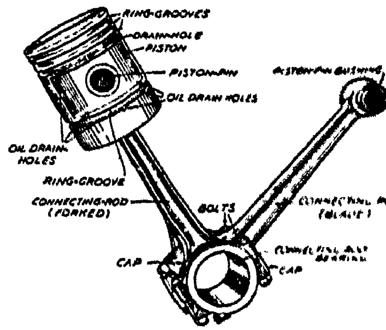


FIG. 72.—Typical connecting rod construction for V-type engine.

Since, in an eight-cylinder, four-cycle engine, all eight cylinders must fire and complete all their events in two revolutions of the crankshaft, or 720 deg., the angle passed through by the crankshaft between successive explosions will be 720 deg. ÷ 8 = 90 deg. This means that a power impulse is transmitted to the

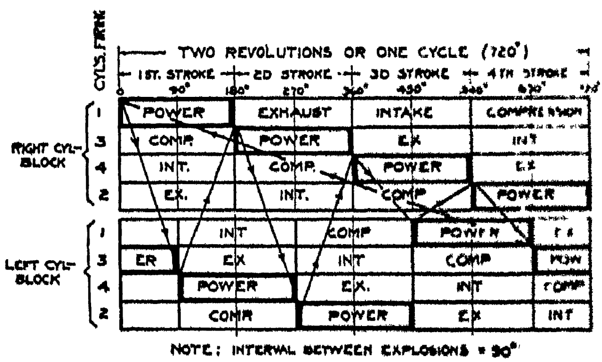


FIG. 73.—Relation of events in an eight-cylinder, 90 deg., V-type engine firing 1-3-4-2 in each block.

crankshaft every one-fourth revolution, or four times per revolution. Thus the power impulses of the eight pistons will be equally spaced and overlap each other one-half, as indicated in the diagrams shown in Figs. 73 and 74. Because of this overlapping of power impulses, the first half (the stronger half) of each power

stroke from the left cylinder block reinforces the last half (the weaker half) of the preceding power impulse from the right cylinder block, and vice versa. Consequently, there is almost a constant stream of power being delivered by the crankshaft to the driving wheels. From the standpoint of ignition, an ignition spark must be provided every 90 deg. of crank travel. The spark must occur first in one cylinder block, then in the other. The firing order of the Cadillac eight-cylinder engine is 1-3-4-2 in each block.

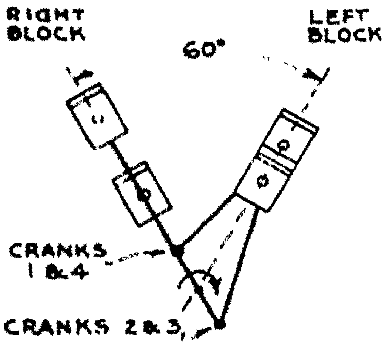
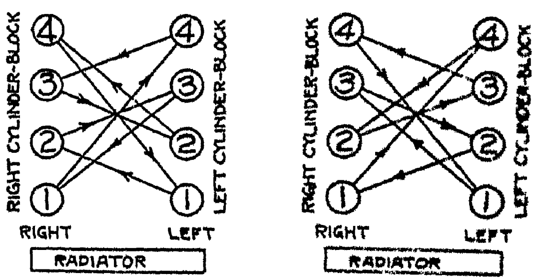


FIG. 34.—Front view of crankshaft and connecting rod arrangement for 60 deg., V-type engine showing pistons Nos. 1 and 4 in right block on top dead center position.

61. The Eight-cylinder, 60-deg., V-type Engine with Cranks in Same Plane. The Lincoln eight-cylinder engine is a typical example of the 60-deg., V-type, eight-cylinder-engine construction. The outstanding feature of this engine over the standard V-type construction is that the angle between cylinder blocks has been reduced from 90 to 60 deg. This was done in an attempt to reduce engine vibration. Since a four-cylinder-type crankshaft, having 180 deg. between cranks, is used, it is evident that, with the cylinders set at 60 instead of 90 deg., the angles passed through by the crankshaft between successive explosions will be unequal, namely, 60 and 120 deg.; that is the crank passes through 60 deg. from the time a cylinder in the right block fires until the next one in the left block fires and 120 deg. from the time a cylinder in the left block fires until the next one fires in the right block. In other respects, the engine operates the same as any standard V-type eight-cylinder engine. The firing order for each block of the Lincoln is 1-2-4-3.

62. Firing Orders of Eight-cylinder V-type Engines. The two typical firing orders used in standard types of eight-cylinder V-type engines are illustrated by the diagrams shown in Figs. 75*A* and *B*. There are naturally two firing orders, since the engine is a combination of two four-cylinder engines, and a four-cylinder engine may have two firing orders.

In the two firing-order charts shown in Fig. 75, it may be seen that the firing order in either cylinder block is in accordance with that of the usual four-cylinder engine. In Fig. 75*A* the firing order is 1-3-4-2 in each block, while in Fig. 75*B* the firing order in each block is 1-2-4-3, assuming in each case that the cylinders are numbered 1 to 4 back from the radiator. The firing order is



(*A*) (*B*)

FIG. 75.—Firing order charts for eight-cylinder V-type engines.

generally the same in both cylinder blocks, the reason being that the same camshaft and cams usually operate the valves in both cylinder blocks.

Method of Determining Firing Order.—In many cases the firing order of the engine is marked on the engine or distributor head, but, in case it is not the firing order may be determined by turning the engine over slowly by hand and testing the order of compression in one cylinder block.

If the order of compression in one block is found to be 1-3-4-2, then the complete firing order of all eight cylinders may be written as follows, starting with No. 1 in the right block: namely, 1R-4L-3R-2L-4R-1L-2R-3L, which corresponds to the chart shown in Fig. 75*A*. From a study of these numbers it will be found that the sum of each successive pair of numbers equals 5. This fact provides an easy way of remembering the method. Likewise, if the firing order in one block is found to be 1-2-4-3, the complete firing order of all eight cylinders will be 1R-4L-2R-3L-4R-1L-3R-2L, where again it will be noted that the sum of each successive pair of numbers equals 5.

63. The Cadillac Eight-cylinder Engine, Type V-63.—The 1924 model Cadillac eight-cylinder engine, type V-63, differs from all former models of eight-cylinder V-type construction chiefly in the design of the crankshaft. It has a balanced crankshaft with cranks in two planes 90 deg. apart instead of 180 deg. as in former models which used a standard four-cylinder-type crankshaft. The advantages claimed for this construction are: a more perfect balancing of the reciprocating forces and a reduction of engine vibration to a minimum.

In Fig. 76*B* is shown the general arrangement of the cranks, while Figs. 76*A* and *C* show the front-end view and the firing-

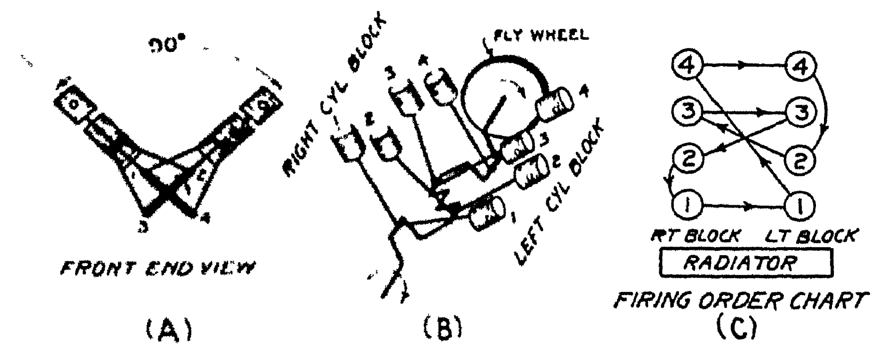


FIG. 76.—Skeleton diagram and firing order chart for Cadillac "Eight," type V-63 (1924).

order chart respectively. The firing order in each block is not in accordance with that for the usual four-cylinder engine, due to the 90-deg. arrangement of the cranks. Because of this arrangement, the method previously described for determining the firing order for an eight-cylinder V-type engine does not apply. Assuming that the cylinders are numbered from 1 to 4 back from the radiator as in Fig. 76*C*, the firing order is 1R-1L-4R-4L-2L-3R-3L-2R.

64. The Packard Single Eight Engine.—A skeleton diagram of the Packard eight-cylinder engine, known as the "Single Eight," is shown in Fig. 77. All eight cylinders are in a row. The crankshaft is a combination of two four-cylinder crankshafts, the cranks of which are arranged in two planes 90 deg. apart. In this engine, an attempt has been made to eliminate vibration,

and in so doing a crankshaft of fairly large diameter with a bearing between each crank (totaling nine) has been used. The firing order is 1-3-2-5-8-6-7-4. The angle between explosions is 90 deg.

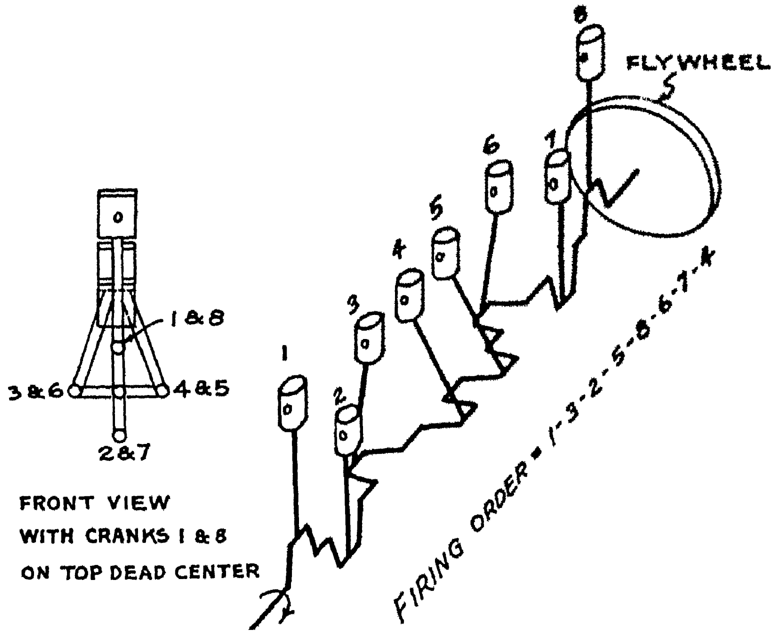


FIG. 77.—Skeleton diagram of Packard straight eight-cylinder engine.

65. The Twelve-cylinder Engine. A typical example of a twelve-cylinder engine is shown in Fig. 78. It is constructed on the V-plan similar to the eight-cylinder engine. In fact, it is a further development of the eight-cylinder engine, in that it may be considered a combination of two six-cylinder engines operating on a common crankshaft of the six-cylinder type.

In this type of engine, twelve cylinders must fire in two revolutions, or six cylinders per revolution; consequently, the crank angle between explosions will be 360 deg. divided by 6, or 60 deg. The connecting rods are arranged two on a crank, similar to the construction for an eight-cylinder engine. The power impulses occur at equal intervals of 60 deg. and overlap each other, as may be seen by a study of Fig. 79.

The Firing Order.—Since the explosions occur first in one cylinder block and then in the other, as in the usual eight-cylinder V-type engine, the firing

order in each cylinder block will be like that of the usual six-cylinder engine, namely, either 1-4-2-6-3-5 or 1-5-3-6-2-4. Diagrams representing the two typical firing orders are shown in Figs. 80A and B.

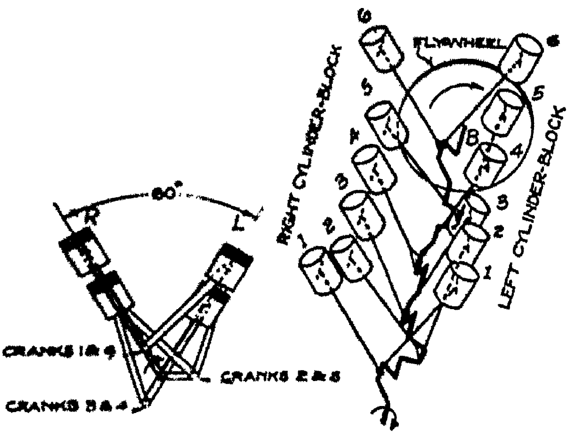


FIG. 78.—Arrangement of cranks and connecting rods in a twelve-cylinder V-type engine firing 1-4-2-6-3-5 in each block.

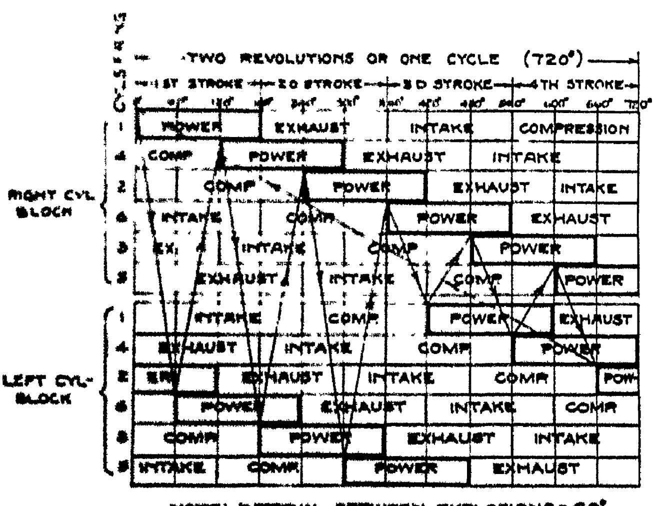


FIG. 79.—Relation of events in twelve-cylinder, 60 deg., V-type engine firing 1-4-2-6-3-5 in each block.

In case the firing order is not known, it may be determined in the manner explained for the eight-cylinder engine, that is, by determining the order of compression in each block. If the order of firing in one block is found to

be 1-4-2-6-3-5, the complete firing order of all twelve cylinders may be written as follows, starting with No. 1 in the right block, namely, 1R-6L-4R-3L-2R-5L-6R-1L-3R-4L-5R-2L. On the other hand, if the order of firing in each block is found to be 1-5-3-6-2-4, the complete firing order will be 1R-6L-5R-2L-3R-4L-6R-1L-2R-5L-4R-3L. From a study of the numbers in each firing order, it will be noted that the sum of the successive pairs of numbers always total 7. This makes either firing order very easily worked out, after the firing order in one block is determined.

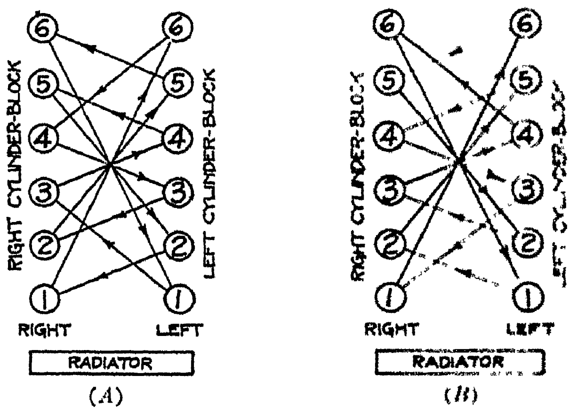


FIG 80.—Firing order charts for twelve-cylinder engines. (A) Firing 1-4-2-6-3-5 in each block. (B) Firing 1-5-3-6-2-4 in each block.

66. The Liberty Twelve-cylinder Aircraft Engine. In some twelve-cylinder engines designed for aircraft purposes, an angle different than the usual 60 deg. has been used between cylinder blocks. A very good example of this is found in the Liberty twelve-cylinder aircraft engine, Fig. 81, which was developed during the World War.

In this engine the cylinders are set at an angle of 45 deg. The chief reasons for this smaller angle are: (1) to make the engine more compact, so as to reduce head-air resistance, and (2) to have the vibrations due to the reciprocating parts (pistons and connecting rods) more in a vertical direction.

In general, the crankshaft and the other engine parts of the Liberty Twelve are similar in design to the parts of many other twelve-cylinder engines. The general arrangement of connecting rods is the same as for the 60-deg. V-type engine, as shown in Fig. 78. The chief difference, however, is the unequal intervals between explosions in the two cylinder blocks. These explo-

sions occur at intervals of 45 and 75 deg. respectively, since the pistons in the opposite cylinder blocks reach their head-end, dead-center positions 45 and 75 deg. apart. It should be remembered that the twelve-cylinder crankshaft is the same as used in the six-cylinder-type engine, the cranks being 120 deg. apart. Thus, if one firing interval is 45 deg., the other interval must be 120 deg. minus 45 deg., or 75 deg.

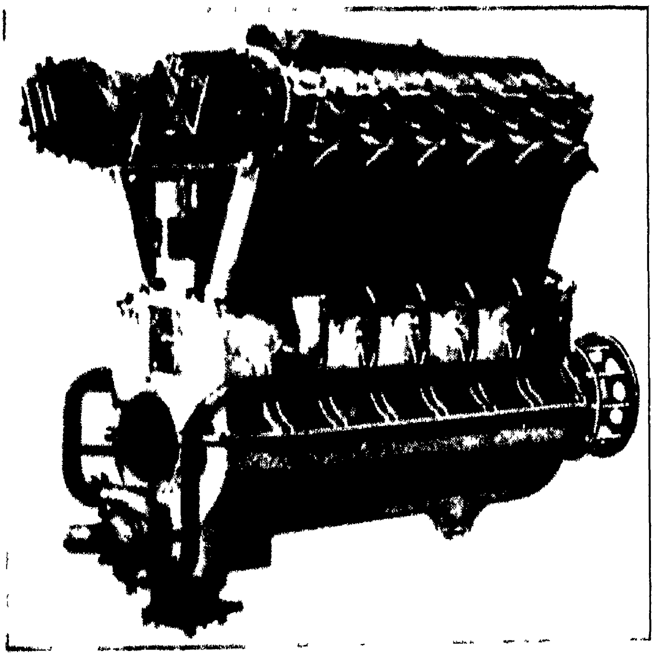


FIG. 81. The Liberty twelve-cylinder aircraft engine.

The firing order of this engine is 1L-6R-5L-2R-3L-4R-6L-1R-2L-5R-4L-3R. The cylinders are numbered from 1 to 6 beginning at the distributor end, the left cylinders being those at the left when viewed from the pilot's seat.

The engine naturally will not run as smoothly as the twelve-cylinder engine of the 60-deg. type because of the unequal firing angles. The vibrations, however, are more of a vertical nature and this advantage offsets to a certain extent the disadvantage of unequal firing angles.

ELEMENTS OF MAKE-AND-BREAK AND JUMP-SPARK IGNITION

67. Requirements of Automotive-engine Ignition. The function of the ignition system is to provide a means of igniting or setting fire to the fuel charge within the engine cylinder each time the piston therein nears the top end of its compression stroke. In its true sense *ignition* means the complete burning of the fuel charge in the cylinder. The process of burning, however, is usually referred to as the *combustion of the fuel*, while *ignition* refers to the initial act of setting it on fire.

In the past, many methods of producing ignition, such as the open flame, the hot tube, the hot bulb, the heat of compression, and combinations of these, were employed. None of these methods, however, have been found practical for automotive service, which requires that an engine start quickly in cold weather yet operate satisfactorily through a wide range of speed from no load to full load. The electric spark has been found the only means of ignition to meet these requirements, because electricity is readily and accurately controlled and because the electric spark gives almost instantaneous delivery of the necessary heat to start ignition.

When it is considered that many of the modern four-, six-, eight-, and twelve-cylinder engines run up to 3,000 and even 4,000 r.p.m., requiring as many as 250 sparks per second, it will be realized that the proper action of the ignition system in supplying a spark in each cylinder at the proper time is of utmost importance.

68. Make-and-break and Jump-spark Ignition.—Two methods of electric ignition have been used, namely, the *make-and-break* and the *jump-spark*. For automotive purposes the latter method has been universally adopted. The make-and-break method, however, will still be found on many low-speed engines

of the stationary type. It is also suitable for engines having high compression of 150 lb. and over.

The *make-and-break* ignition system is very simple in its construction and wiring, as may be seen from Fig. 82. This diagram shows a typical single-cylinder stationary-engine installation designed to operate from either a battery or a magneto. The principal component parts are a source of current, either a battery or a magneto of low voltage, coil, igniter, switch, and the necessary wiring for the connections.

This type of system utilizes for ignition purposes the spark produced whenever a circuit carrying a current is suddenly opened or broken. Since such a spark is of high temperature and practically instantaneous in action, it can be used very nicely to *ignite* the gas-engine charge. The principle employed is described in Art. 69.

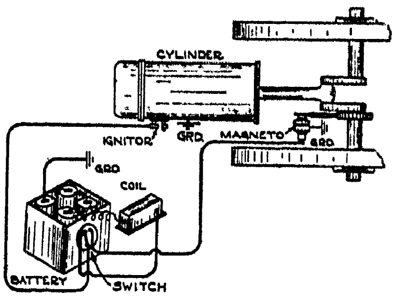


FIG. 82.—Typical wiring of stationary engine using both battery and magnet make-and-break ignition.

In the *jump-spark* ignition system, current is obtained from either a battery or a magneto, but it is first transformed from low voltage to high voltage by means of an *induction coil*. The high-voltage current is then made to jump the points of a *spark plug* inside the engine cylinder and the spark thus created sets fire to the combustible gases.

Although make-and-break ignition has practically given way to jump-spark ignition for automotive purposes, the operation of the make-and-break system should be thoroughly understood because of the similarity in the action of the ignition coils used in both systems.

69. The Low-tension Coil for Make-and-break Ignition. The principle employed in make-and-break ignition may be illustrated by the arc obtained when the two leads from a set of dry cells or a storage battery are struck together and quickly snapped apart. On account of the interruption of the current, a bluish-white spark will be produced at the point of separation. A spark produced in this manner is inefficient. Therefore, to make it both efficient and more effective for ignition purposes, a coil of insulated copper wire wound on a soft-iron core is connected in series with the batteries and *igniter*, as shown in Fig. 83. The core is usually made either of thin, soft-iron laminations or a bundle of soft-iron wire, so that it will magnetize and demagnetize quickly. Such a coil is usually termed [illegible]

coil, because if a current through the coil is suddenly interrupted by breaking the circuit a "flashy" spark of considerable intensity or "kick" will occur at the point of current interruption. In practice, the spark thus produced occurs between the igniter contacts inside the cylinder and is used to ignite the fuel charge.

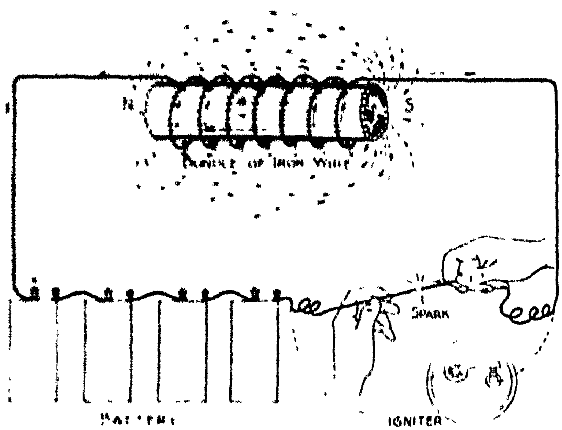


FIG. 83.—Principle of the low tension coil.

The large flashy spark produced when the coil is used, in comparison with the small bluish-white spark obtained without it, indicates that the action of the coil is such as to bring about this change, and that its use is of vital importance.

Briefly, the change in intensity of spark is brought about because of the inductive effect of the coil during demagnetization. In Sec. II it was explained that whenever a wire is made to cut a magnetic field, or a magnetic field is made to cut a wire, an induced voltage is set up in the wire proportional in strength to the number of magnetic lines of force cut per second. It is also evident that the direction of the induced voltage will be in accordance with the direction at which these lines of force are cut.

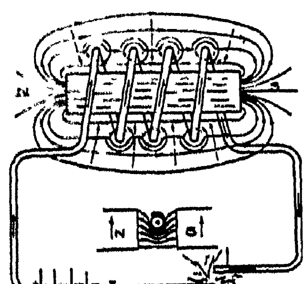


FIG. 84.—Self-inductance produced by a falling current in a coil.

From a study of Fig. 83 it will be seen that, upon the demagnetizing of the core at the moment the circuit is broken, the magnetic lines of force will move rapidly toward the core and, in so doing, will cut each turn of wire, as in Fig. 84. This cutting of the wire by the collapsing lines of force will set up a whirl of magnetic lines around each turn of wire and will induce a voltage in the coil of such polarity as to cause a

current to flow in the same direction as the original magnetizing current from the batteries. This induced voltage is only momentary, since it is produced by the collapsing lines of force, but, due to the multiplying effect of the turns, it may reach a maximum voltage across the entire coil of 200 to 250 volts, depending upon the number of turns and the design of the coil. Furthermore, since this voltage is in series with that of the battery and is produced at the moment of igniter-contact separation, it is sufficient to break down the comparatively small air-gap resistance between the contacts for a brief time, causing a very hot, yellow, flashy arc to be drawn out between them.

This arc is accompanied by a heavy momentary current which is produced through the combined action of induction in the winding and the discharge from the battery. Because an arc is a fairly good conductor of electricity, this current flow will tend to prolong the demagnetization period of the core, with the result that the arc is maintained for a short period of engine crankshaft rotation.

Hydraulic Analogy of Kick Coil.—The action of a kick coil may be compared to the *water hammer* produced in a pipe line, when, with the water flowing at full rate, the valve is closed suddenly. The sudden stoppage of a column of water will, due to its momentum, produce a terrific blow on the valve, known as *water hammer.* The resultant instantaneous pressure may be several times that of the ordinary pressure which caused the water to flow when the valve was open. It will also be noted that this instantaneous or kick pressure is in the same direction as the original pressure, thereby tending to maintain the flow of current just as the kick voltage does in the low-tension make-and-break coil. The same principles, it will be found, apply also to the action of the primary winding in the jump spark type ignition coil.

70. Effect of Self-induction upon Speed of Ignition Coil. The inductive effect produced during the magnetization and again during the demagnetization of an electromagnet is called *self-induction.* It was explained in the preceding article that a momentary voltage was induced in the coil winding due to the collapsing lines of force upon the interruption of the magnetizing current. Conversely, a similar inductive effect is produced in the coil winding by the expanding of magnetic lines of force which takes place during the period of coil magnetization immediately following the completion of the circuit by the closure of the igniter contacts. Furthermore, it will be found that since the magnetic lines of force cross the winding outward as illustrated in Fig. 85, just opposite to their direction of travel when the coil demagnetizes, the induced voltage will also be opposite in direction to the applied voltage. In fact it will oppose the voltage of the battery which causes the current to flow.

The result is a retarded magnetization of the coil, a small fraction of a second being required before the magnetizing current is fully established to a value where, according to *Ohm's law*, $I = \frac{E}{R}$. The inductive effect and, consequently, the time required for the coil and core to become fully magnetized depend upon the length, cross-sectional area, shape, and quality of the iron used for the core, the number of turns of wire in the coil, etc. The result is that some ignition coils are *faster* than others, an important fact which should be considered in replacing a defective coil.

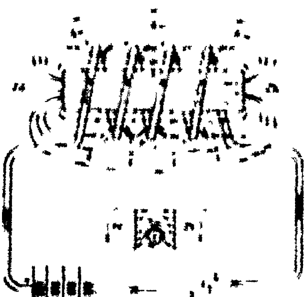


FIG. 85.—Self inductance produced by a rising current in a coil.

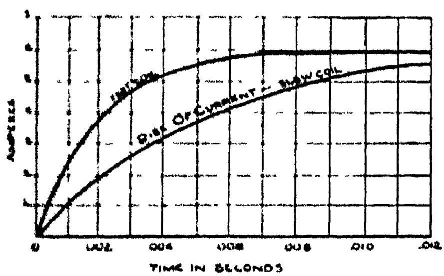


FIG. 86.—Curves showing current rise in slow and fast ignition coils.

Curves illustrating how the current rises in slow and fast typical ignition coils are shown in Fig. 86. From these it will be noted that the time required for the current to rise to full value is 0.006 sec. for the fast coil and 0.012 sec. for the slow coil. It will further be seen that the period of igniter contact closure should equal at least the time required for the current to rise to full value, since, if it is less, the contacts will open before the coil is fully magnetized, thereby materially reducing the intensity of the ignition spark.

71. Igniters for Make-and-break Ignition.—The igniter used in make-and-break ignition usually consists of one stationary and one movable electrode mounted in an iron block in such a manner that, when the block is bolted to the engine cylinder head, the electrodes extend within the combustion chamber so as to be in contact with the combustible gases. The contacts between

which the arc is drawn must be composed of a metal or alloy, preferably platinum, which will withstand both high temperature and oxidation. However, due to the high cost of platinum, this metal is rarely used, it being replaced by substitutes such as nichrome—an alloy of nickel and chromium tungsten, or an alloy of nickel and iron. As a rule, one electrode, usually the movable one, is grounded, so that the engine acts as a conductor, taking the place of one wire as shown in Fig. 82.

Open- and Closed-circuit Igniters.—When a battery is being used as a source of current, it is highly desirable to conserve the current as much as possible in order to prevent a rapid discharge. Consequently, since the current needs to be "On" only long enough to excite the coil core with magnetism to the degree required to give proper ignition, it is evident that a longer duration would result in a waste of current. Therefore, the igniter can be of the *open-circuit type*, the contacts being adjusted to close only for a sufficient period at the highest operating speeds to provide good sparks.

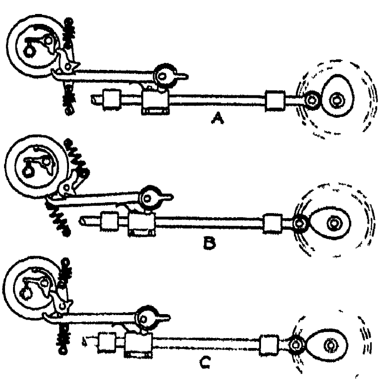


FIG. 87.—Typical slide-rod type make-and-break ignition mechanism. (*A*) At start. (*B*) At moment of trip off. (*C*) After trip-off.

When a magneto is used as a source of current supply, it is not important to conserve current, and the igniter contacts may remain normally closed and be opened only when a spark is desired. Such an igniter is known as a *closed-circuit type*. The closed circuit type has the advantage over the open-circuit type in that the contacts remain cleaner and, consequently, better sparks are produced. Whenever a magneto is used, the use of a kick coil is seldom necessary, since the armature or core of the magneto winding will provide a sufficient inductive effect to give good ignition sparks.

In both types of igniters, the contacts may be arranged either to simply touch, before they are snapped apart, or to make a wiping contact. The latter method has the advantage of a cleaner contact but requires more frequent adjustment to compensate for contact wear. A wearing away of the contacts will naturally reduce the period of contact closure, causing the contacts to open earlier and the time of spark to be advanced.

The Igniter Trip Mechanism.—The igniter trip mechanism may be operated in a number of ways, the usual method being by a push rod operated from a cam or gear driven at one-half crankshaft speed in a four-cycle engine. Figure 87 shows a typical installation. The time of spark may be adjusted by varying the time of the trip-off. Where a retard of the spark

is desired, such as in starting stationary engines of over 6 hp. which are hard to crank, a small lever is usually supplied which, when turned in one direction, delays the action of the trip mechanism, thus retarding the spark. However, this retard lever should be turned back to the advanced position after the engine has started.

72. The Induction Coil. When the current for automobile ignition is derived from a set of *dry cells*, a *storage battery*, a *low-tension magneto*, or a *generator*, the voltage usually ranges from 6 to 12 volts. This voltage is much too low to force a spark to jump the gap between the spark-plug points, especially when they are under compression inside of the engine cylinder. Consequently, the low-voltage current must first be transformed

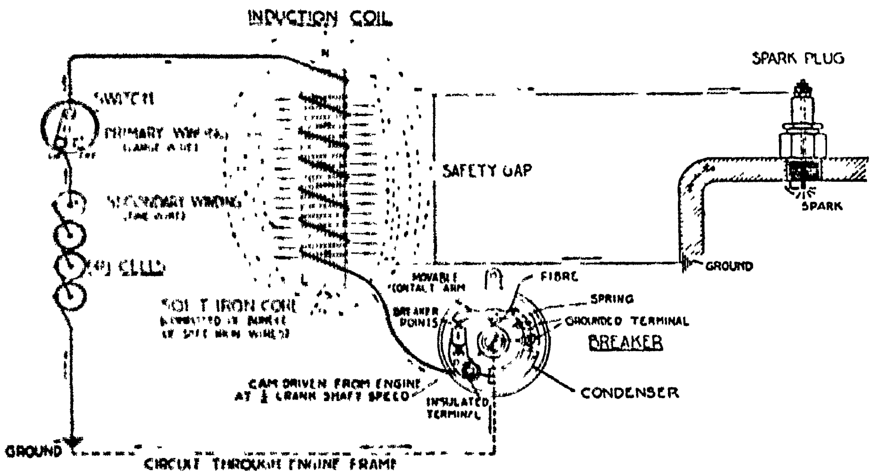


FIG. 88. Circuits of simple jump-spark ignition system for single cylinder engine.

to a current of high voltage by a special transformer known as an *induction coil*.

Induction coils may be of either the *vibrating* or the *non-vibrating* type. In either case the general construction and the principle of operation are much the same. The principal difference is that the vibrating-type induction coil operates with a *timer* and gives a shower or series of sparks at the plug, while the non-vibrating type of coil operates with a *breaker* and gives but a single spark at the plug. The non-vibrating coil is the most popular for automobile ignition. Its application to a jump-spark ignition system is illustrated in Fig. 88.

The induction coil consists essentially of a *primary* and a *secondary* winding, both wound on a core of soft iron. This core usually consists of a bundle of soft-iron wires, the core measuring about ½ to ¾ in. in diameter and 4 to 6 in. long. The core may also consist of thin, soft-iron laminations as shown in Fig. 89.

The *primary* winding, which is connected to the source of current supply, consists usually of several layers of insulated copper wire, ranging in size from Nos. 16 to 20, B. & S. gage. The wire is wound around the core so as to make it an electromagnet. In fact, its construction corresponds

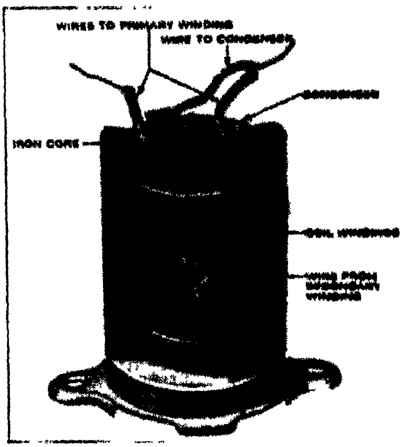


FIG. 89.—Construction of Remy induction coil using laminated W type core.

to that of the make-and-break kick coil. The insulation of the wire usually consists of layers of cotton fiber, though in some cases an enamel insulation is used.

The *secondary* or high-tension winding, to which the spark plug is electrically connected, is wound usually outside of the primary coil, but is well insulated from it. It is made up of several thousand turns of enameled or silk-covered copper wire, usually of about Nos. 36 to 38 B. & S. gage. The secondary winding is sometimes made up of many layers, each layer running the entire length of the coil. The layers are insulated from each other by paraffin waxed paper. In another type of construction, the winding is made up of several narrow spools, or *pancakes*, assembled over the primary coil with suitable insulation between. The adjacent ends of these pancake coils are connected so that their windings are in series.

The secondary winding of an induction coil used for gas-engine ignition produces at times a momentary pressure of 10,000 to 20,000 volts. The quality of the insulation and construction, therefore, must be such as to

prevent the induced voltage from escaping at some other point than at the spark-plug gap. The normal voltage necessary to jump the spark-plug points under compressions of 70 to 75 lb. with the points properly adjusted (0.025 to 0.030 in.) is usually from 5,000 to 6,000 volts. This voltage, however, must be increased in proportion to the increase in compression. Each turn of the winding develops its share of the voltage of the whole coil. For example, if, in a secondary winding having 10,000 turns, 1 volt is induced per turn, the total voltage will be 10,000 volts.

In coils where the winding is made in long layers, the full voltage developed exists between the top and the bottom layers. There is then a chance for the spark to leap between the layers, which must be protected by high-quality insulation. It is a common practice to run a layer of thin waxed paper between the layers of wire and to impregnate the whole winding with wax. For this reason the coil is not affected by dampness and there is less chance for the winding to *break down* or to *short-circuit* due to defective insulation. A breakdown of the secondary winding consists of a puncturing of the insulation, thereby reducing the resistance so that current will flow between the layers of the winding, causing an arc within the coil instead of at the point where the spark is desired. In the pancake type of windings, the terminals of the secondary coil are separated the full length of the coil, the voltage difference between the successive reels or pancakes being only a fraction of the total voltage.

The secondary winding of a coil should also be well insulated from the primary winding. For insulating purposes, a material having a high *dielectric* or insulating strength should be used. The best dielectric materials are glass, mica, rubber, paraffined paper, empire cloth, and porcelain. For insulating the coil windings, empire cloth is particularly suited, since it has a high dielectric strength and is flexible and comparatively thin. Mica is also very good.

73. Operation of the Simple Jump-spark Ignition System.—Figure 88 shows a circuit diagram of a simple ignition system for a single-cylinder four-cycle engine. The induction coil is of the *non-vibrating* type operating with a breaker for making and breaking the primary current. Unlike the make-and-break system, no spark is desired at the point of circuit interruption. Therefore, a condenser is connected across the breaker contact points. This protects the points against pitting and assists the primary coil in inducing a high voltage in the secondary winding. The breaker points are normally held closed by spring tension and open only when the lobe of the cam lifts the movable contact arm. The cam is driven by the engine and, on engines of the four-cycle type, rotates at one-half crankshaft speed in order to produce one spark in two revolutions of the crankshaft.

Obviously, it must be timed with the engine so that the spark will occur when the piston is nearing the top end of its compression stroke.

The operation of the system shown in Fig. 88 is as follows: When the switch is turned to the "On" position and the cam is in such a position that the breaker contacts are closed, current flows through the primary circuit from the positive (+) terminal of the dry cells, through the switch and primary winding of the coil (magnetizing the core as indicated), to the insulated terminal of the breaker. From here it crosses the breaker contacts and passes through the contact arm to the ground, returning through the ground to the negative (-) or grounded terminal of the dry cells, thus completing the circuit. (A ground circuit is that part of the circuit in which the current travels through the engine and chassis frame. The frame, or *ground*, acts as a conductor the same as one wire.)

When the primary current is interrupted due to the cam lobe lifting the breaker contact arm, causing the contact points to separate, the core immediately demagnetizes. In so doing the magnetic lines of force collapse toward the core, cutting each turn of both the primary and the secondary winding. This causes a momentary kick voltage to be set up in the primary circuit, just as in the make-and-break system, and a high voltage is produced in the secondary circuit, due to the large number of turns in the secondary winding. Furthermore, the direction of induced voltages in both windings will be around the core in the same direction as that of the original magnetizing current.

By having several thousand turns of fine wire in the secondary winding, a sufficiently high voltage is induced in the secondary circuit to break down the resistance across the gap of the spark-plug points, thus completing the circuit and giving the desired ignition spark within the cylinder. The path followed by the secondary current, as shown by the arrows, leads from one end of the secondary winding to the spark-plug terminal through the insulated electrode of the plug, jumping the gap between the plug points to the engine frame, and returning through the engine frame to the other end of the secondary winding. It should be remembered that in the jump-spark system the primary winding and its current are used for magnetizing the core, while the current which is induced in the secondary coil when the primary circuit is broken is used for the ignition spark.

Just as in the make-and-break coil, a voltage is induced in both the primary and the secondary windings when the core is being magnetized as well as when it is being demagnetized. However, because the expanding lines of force cut the windings in an outward direction, inducing a voltage in the primary winding to oppose the battery voltage, the core magnetizes more slowly than it demagnetizes. Consequently, the induced secondary voltage during the building-up period is not sufficiently high to break down the resistance of the gap across the spark-plug points. On the other hand, when the primary circuit is broken, the core, assisted by condenser

action, demagnetizes very rapidly (much faster than in the make-and-break coil) and induces a current of high voltage in the secondary winding.

74. The Condenser. The condenser, as shown in the circuit diagrams of Figs. 88 and 90, is connected to the primary circuit

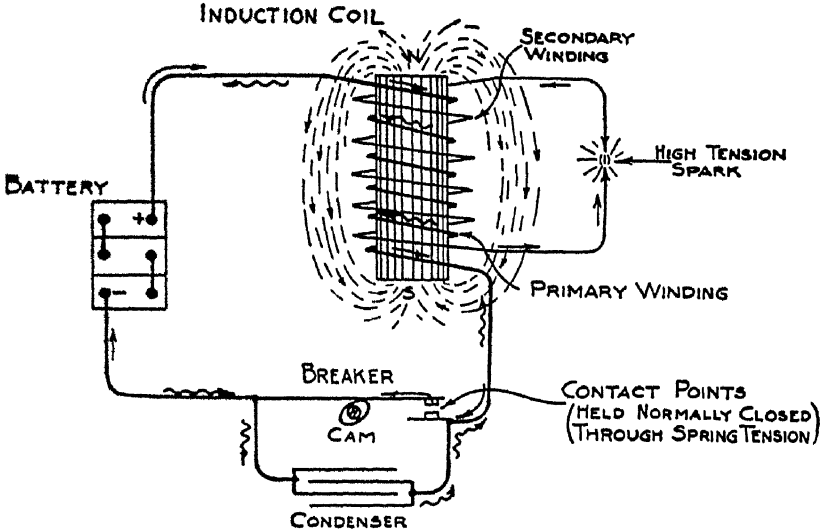


FIG. 90. Connections of condenser in jump-spark ignition system.

in parallel with the interrupter or breaker contacts. It is constructed of strips or sheets of tin foil insulated by thin sheets of parafined paper or mica of 0.002 to 0.003 in. in thickness. The

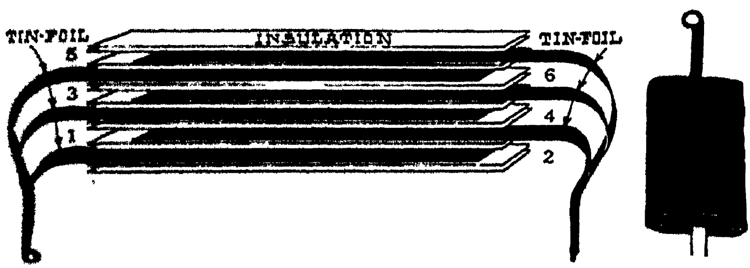


FIG. 91. Diagram showing construction of condenser. At the right it is completely assembled.

alternate layers of tin foil are connected in parallel, forming two groups, each group being provided with a terminal for external connection as in Fig. 91. With proper insulation *there is no electric circuit through a good condenser.* If current passes through

the condenser, it is short-circuited or *leaky*, and must be repaired or replaced.

Action of Condenser.—When the break of the primary circuit occurs, the induced-kick voltage in the primary, Fig. 90 (which is in the same direction as the original battery current and which would otherwise cause an arcing of the contact points), caused by the collapsing magnetic lines of force, is impressed across the condenser and charges it. The side of the condenser which receives the surge is temporarily charged *positive* and the other side *negative*. Instantly, the condenser discharges back in a reversed direction through the primary winding and battery (or other source of current) in an attempt to equalize the potential of the two sides of the condenser. As the backward surge of current is opposite in direction to the original magnetizing current, it assists in quickly reducing the magnetism of the core to zero, thus speeding up the collapsing lines of force and thereby aiding in securing the maximum induced voltage in the secondary winding. In reality, the current surges, or oscillates, from one side of the condenser to the other several times before it finally dies out. In Fig. 90 the initial condenser discharge is represented by the crooked arrows.

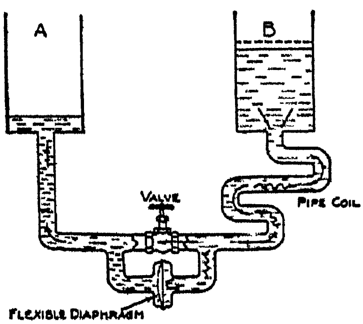


FIG. 92.—Hydraulic analogy explaining action of ignition condenser.

Hydraulic Analogy.—The action of the condenser may be compared to that of the flexible diaphragm shown in Fig. 92. When the valve is closed suddenly, cutting off the flow of water from the tank *B* through the coil of pipe into the tank *A*, the water depresses the diaphragm for an instant, due to the momentum attained by the water. The diaphragm will then rebound immediately, forcing a surge of water back and forth several times before it finally comes to a standstill in the pipe. This surging action of the water may be compared to the surging or oscillating of the electric current upon successive discharges of the condenser.

Since the condenser is subjected to the full-kick voltage of the primary coil, namely, the 150 to 250 volts impressed across the contact points at the instant the primary current is interrupted, it is evident that a good dielectric material between the tin foil plates is necessary in order that no connection between the opposite plates may occur through a puncturing

of this material. If a flashy spark occurs at the interrupter points, it is evidence that the condenser has become either broken down (short-circuited) or disconnected. It might also be too small for the size coil with which it is used.

Condenser Capacity. The capacity of a condenser depends on the size, number, and arrangement of the tin foil plates, and upon the thickness and quality of the dielectric material between them. The actual number of square inches of tin foil needed in a condenser depends upon the size of the wire and the number of turns in the coil windings, the shape and quality of the iron core, and the speed of the interrupter contact break. Its capacity is usually about one-half *microfarad* (the microfarad is the unit of electrical capacity). The action of a good condenser of proper capacity usually results in intensifying the secondary voltage nearly 25 times. It should also eliminate arcing at the breaker points when they are separated, thus preventing rapid pitting and wearing away of the contact points.

Condenser Mounting -The condenser is usually mounted either in the breaker unit or in the coil housing, preferably as near to the breaker contacts as possible in order to be most effective. In either location it should be well protected against physical damage and moisture.

75. Breakers for Jump-spark Ignition.—The breakers used in jump-spark ignition vary considerably from those used in the make-and-break system, being much lighter in construction than make-and-break igniters are because they do not have to withstand the intense heat of the combustion chamber and are not subjected to such rough usage. On the other hand, the breaker must provide accurate firing at high speed. Therefore, the reciprocating parts must be light in weight, yet strong. This necessitates high-grade materials and workmanship.

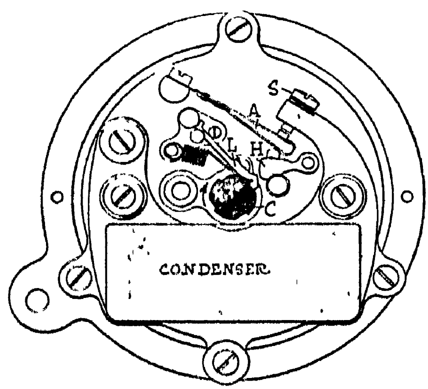


FIG. 93.—Typical open-circuit type breaker. (*Atwater-Kent.*)

The breakers used in the jump-spark system are divided into two general classes similar to those in the make-and-break system, namely, *open-circuit breakers* and *closed-circuit breakers*, typical examples of which are shown in Figs. 93 and 94 respectively.

In the open-circuit-type breaker, the contact points remain normally open and are closed only for a short period of time prior to the moment the ignition spark is desired. The distinct advantage of this type of breaker is its economical use of current; in fact, the open-circuit breakers originally developed were for use with dry cells where great current economy is highly desirable. It will also be evident that the sparks produced from such a breaker will be of fairly constant value regardless of engine speed, since the period of contact closure and the speed of contact break are not dependent upon engine speed.

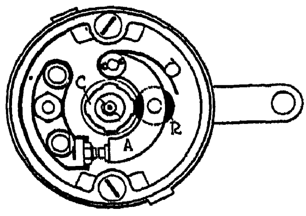


FIG. 94.—Typical closed-circuit type breaker (*Connecticut*).

In the closed-circuit-type breaker, the contact points remain normally in the closed position, being separated only when the movable contact arm is lifted by a lobe of the breaker cam. This type of breaker has for its object the production of especially good sparks at low starting speeds with less intense sparks at high speeds. It is not, however, as economical of current as the open-circuit type. Both types of breakers have their advantages and their disadvantages. These will be discussed in detail in Sec. V.

76. Breaker Contact Points.—The contact pieces or *points*, which make and break the primary circuit, consist usually of two platinum or tungsten pieces of about $\frac{1}{8}$- to $\frac{5}{32}$-in. diameter, one of which is mounted on the movable contact arm while the other is stationary and is supported on the end of a steel adjusting screw. The use of one or the other of these metals is necessitated by the high temperature at which these contacts must operate, thus requiring contacts having extremely high melting points and at the same time offering comparatively low resistance. To prevent burning and pitting of the contact surfaces, the contacts must also be sufficiently hard to withstand the hammering action caused by the rapid closing of the contacts at high speed.

The best all-round material for contact points is a platinum alloy containing approximately 80 per cent platinum and 20 per cent iridium, the iridium being used to give the alloy hardness. Owing to the scarcity and high cost of both platinum and iridium, however, pure tungsten has been found to be a good substitute. Other substitutes, such as silver and nickel, have also been used, but they are not so satisfactory as tungsten and are not to be recommended, since they will pit and burn rapidly, causing faulty ignition. In practice, tungsten contact points

are used almost exclusively for breakers of battery ignition systems, while the platinum contacts are used almost exclusively for magneto breakers, where the duty of the contact points is much more severe. The reason for this is as follows: The primary voltage and the current of the magneto increase gradually with increase in speed, so that at high speeds the momentary *kick* voltage impressed across the breaker points of the magneto upon each break is much higher than it is in the battery ignition system, resulting in more sparking and a higher temperature at which they must operate. On the other hand, in the battery ignition system the voltage of the battery and of the generator remains fairly constant throughout the entire range of engine speeds.

Adjustments of Contact Points.—The adjustment of the contact points will vary somewhat in accordance with their positions on the contact arm, that is, whether the contact is located on the outer end of the contact arm opposite to the pivot, or whether it is located between the pivot and the buffer which bears on the cam. The former method is much more common, since it gives a faster contact opening. With this arrangement the contacts should be adjusted generally to open 0.018 to 0.020 in., or approximately $\frac{1}{64}$ in. This adjustment varies, however, with the type of ignition equipment and the engine on which it is used.

77. The Vibrating-type Induction Coil. The vibrating-coil ignition system differs from the non-vibrating type chiefly in the addition of a vibrator to the coil and the use of a *timer* instead of a *breaker* for opening and closing the primary circuit. A typical vibrating type of induction coil is shown in Fig. 95. The essential parts of the coil are: a core of soft-iron wire, a primary winding of coarse insulated copper wire of Nos. 16 to 20 B. & S. gage, a secondary winding of fine insulated copper wire of Nos. 36 to 38 B. & S. gage, a condenser, and a vibrator.

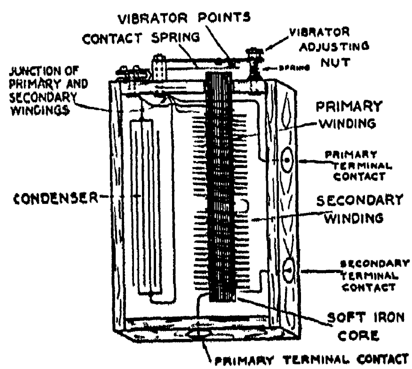


FIG. 95.—Ford vibrating-type ignition coil.

A circuit diagram of a simple jump-spark ignition system using a vibrating coil and timer is shown in Fig. 96. There are two separate and distinct

electric circuits, namely, the *primary* and *secondary* circuits, as in the non-vibrating system. The primary or battery circuit includes the battery, the switch, the vibrator, the primary winding of the coil, the timer, and the condenser, the condenser being connected across the vibrator points. The secondary circuit contains the fine or secondary winding of the coil and the spark plug, no distributor being necessary. When the primary circuit is completed at the timer (which is usually driven by the camshaft of the engine), current will flow from the battery through the primary winding of the coil in the direction indicated by the arrows. The core of the coil thus becomes magnetized, and, as long as the current flows, this core will have

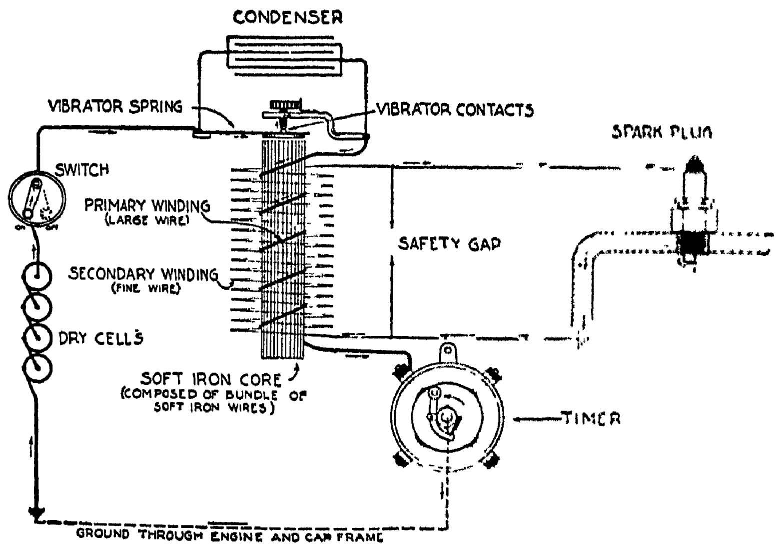


FIG. 96 —Circuit diagram of simple jump-spark ignition system using vibrating coil and timer.

the properties of a magnet. With the circuit completed, the core exerts a magnetic pull on the iron disc or *armature* attached to the end of the vibrator, and in doing so separates the contact point on the vibrator from the stationary contact. This breaks the primary circuit and the current ceases to flow. The core then loses its magnetism and the vibrator returns to its former position. In doing this, it reestablishes the primary circuit and the action is repeated. Thus, as long as the primary circuit is closed by the roller making contact with a segment of the timer, the vibrator will vibrate rapidly, similar to the vibrator of an ordinary electric door bell. This vibration is accompanied by a shower of high-tension sparks at the plug. The sparks begin at the instant the contact is made and last throughout the period of timer contact.

78. Types of Vibrators. The performance of any vibrating-type induction coil is largely dependent upon the design and operation of the vibrator, typical designs of which are shown in Fig. 97. Each type of vibrator has its particular characteristics. In Figs. 97 *A*, *B*, *C* and *D*, it will be noted that the contact is mounted on the vibrator arm *V* and that the break occurs during the beginning of the movement of *W* toward *K* when the latter becomes magnetized. There is also more or less of a bouncing effect when the points come back together after the release of *W*. This tends to cause irregular operation and occasional "missing," particularly in type *A*. In *E* and *F* the contacts are opened very

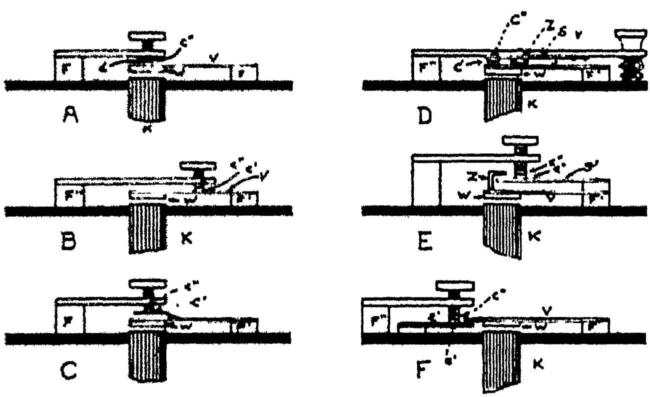


FIG. 97. Types of vibrators

suddenly—in fact, with a hammer break, which is a distinct advantage. Furthermore, after the contacts open, the contact spring tends to act as a drag on the vibrator weight *W*, tending to hasten its return to normal position. However *W* does not stop suddenly with the closing of the contacts, but continues upward until reversed by the action of spring *V* and the renewed pull of *K*. The bouncing of the contact points is thus practically eliminated, thus increasing their life and service.

Another important point is the speed of the vibrator, which controls the number of sparks that occur during timer contact, especially at high speed. The most important points are: strength of *V*, the weight of *W*, the strength of *K* when magnetized, the distance of *W* from *K* when the points are in contact, and the location of the points *C′* and *C″*. The most widely used vibrator

is that shown in *D* since it is used on the Ford car and tractor engine. When properly adjusted, its normal vibration speed is 200 to 300 per second.

79. The Vibrating-coil Ignition System.—Where vibrating coils are used for ignition on a multiple-cylinder engine, it is customary to use a separate coil for each cylinder. These coils are usually of the interchangeable slip type, such as shown in Fig. 95, fitted side by side in an upright box, Fig. 98. This is the type used on the Ford car. The connections for these coils are made by contact springs in the coil box bearing on the metal

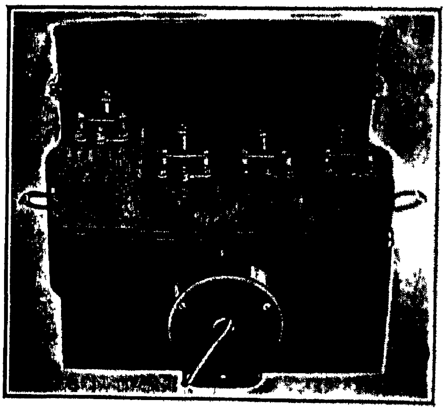


FIG. 98.—Ford four-cylinder coil set.

contacts of the coil as shown in Fig. 95. This design makes it possible to remove any of the coils without disconnecting any of the wiring. The switch on the front of the box permits the primary current from either a battery or a low-tension magnet to be used. This system may also be used with two independent batteries, one being held in reserve.

Figure 99 shows the circuit diagram of a typical vibrating-coil ignition system for a four-cylinder engine, using either dry batteries or a low-tension magneto as the source of current supply. This is the diagram for the Ford system of ignition which is taken up in detail later.

80. The Timer.—The timer is virtually a revolving switch, driven by the engine, for the purpose of connecting the source of primary current supply to the proper vibrating induction coil

at the proper time. It is, therefore, always placed in the primary circuit. The timer used on the Ford engine—practically the only engine using a timer with vibrating coils at the

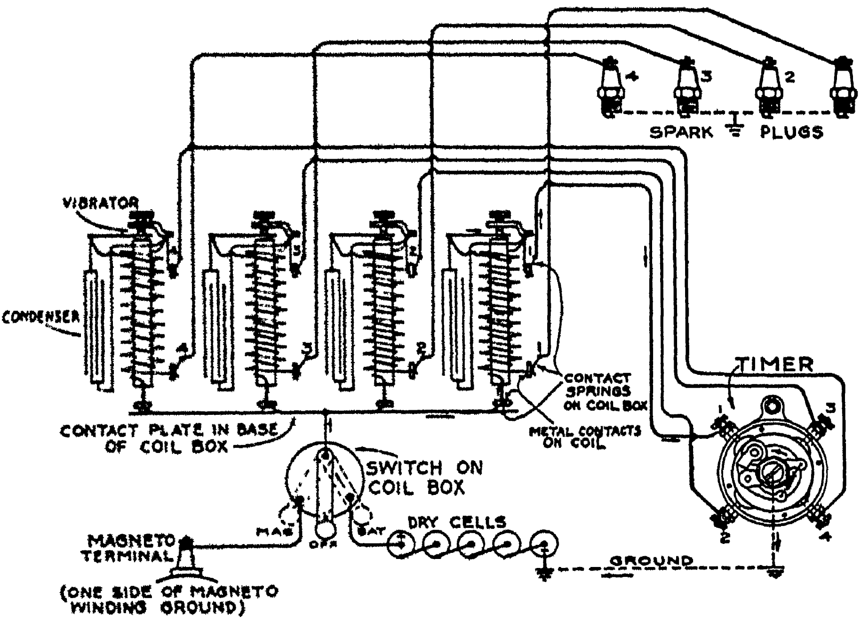


FIG. 99. Circuit diagram of Ford four-cylinder vibrating-coil ignition system.

present time is shown in Fig. 100. The inside or rotating part is fastened to and rotates with the camshaft at one-half crankshaft

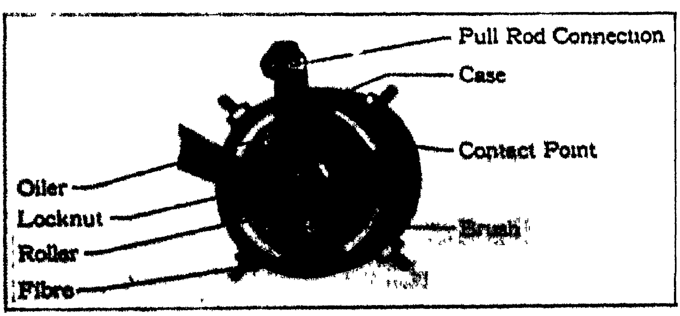


FIG. 100.—The Ford timer.

speed. When the roller comes into contact with one of the four terminals on the timer housing, the primary circuit is completed

through the coil which is connected to that terminal, causing its vibrator to operate and a series of sparks to occur in rapid succession at the plug. The housing of the timer does not turn with the camshaft, but it can be shifted forward or backward with respect to the camshaft and roller, so as to advance or retard the time of the spark.

A large variety of timers, some of which have splendid features, has been produced in an attempt to improve upon the regular Ford timer. However, the operating principle of each must be the same, namely, to complete the primary circuit through the proper coil at the proper time. This calls for considerable accuracy in locating the contacts so as to provide sparks timed alike in all cylinders. The timer must also make positive contacts of proper duration at high engine speeds.

81. Master Vibrators.—A master vibrator is a single vibrator or interrupter connected so as to take the place of the separate vibrators of the coil units on a multi-cylinder engine, thus doing away with separate vibrator adjustments for the different coils. With this system one fast vibrator with a good condenser will produce sparks of like intensity at each of the plugs.

A master vibrator is similar in construction to a vibrating coil, except that it has no secondary winding. It consists of an iron core with primary winding, a vibrator across the points of which is connected a condenser, and a switch. It is connected in the primary circuit in such a way as to be in series with any induction coil used in the coil set. The one vibrator thus operates regardless of which cylinder is firing.

When a master vibrator is installed in connection with coils having vibrators, such as the Ford, a change is made in the coils, by cutting out or short circuiting the condenser and the vibrator of each coil. This is done either by simply screwing down each of the vibrator contacts so that they make firm contact and cannot vibrate, or by short-circuiting each vibrator with a short piece of copper wire. The three-position switch on the coil box is also discontinued and that on the master vibrator used instead. Figure 101 shows a wiring diagram for a four-cylinder coil set with a master vibrator such as is often used on the Ford car. This diagram shows the switch thrown to "magneto" position so the magneto is furnishing the primary current. The firing order is 1-2-4-3. The connection is shown to give a spark in cylinder No. 1.

The demand for such a device as a master vibrator has been brought about by the difficulty experienced in securing uniform adjustment of the various vibrators, by the deterioration of the vibrator points, and by the frequent troubles encountered with defective condensers. It was found about as

cheap to install a master vibrator as to replace the expensive points or to buy new coils. As the condensers and vibrators of the individual coils are inoperative when the master vibrator is used, any defects in those parts will not prohibit their use in the new scheme. The chief advantage of the master vibrator is the fact that sparks of equal intensity are delivered to all the spark plugs by means of a single master-vibrator equipment.

Note.—With the exception of the ignition system used on both the Ford car and Fordson tractor, the vibrating coil ignition system has practically disappeared from automobile use in favor of single spark ignition. However, the vibrator system is still used on many engines for stationary, tractor, and marine service. The vibrator is also incorporated in some high tension dual-magneto ignition systems in order to provide a vibrating spark for starting purposes.

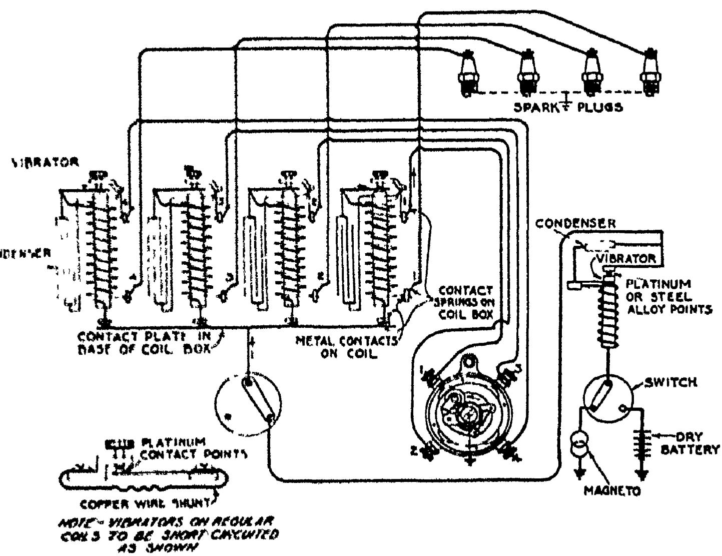


FIG. 101.—Circuit diagram of Ford four-cylinder vibrating-coil ignition system using master vibrator.

82. Voltages Required for Jump-spark Ignition.—As previously stated, the voltage usually required to break down the resistance across the spark-plug points under compressions up to 75 lb. is approximately 5,000 to 6,000 volts, because an air gap offers a very high resistance, which increases in proportion to the increase in pressure. The voltages required to jump various air gaps between sharp points is shown by the curve in Fig. 102. It will be seen from the curve that a gap of ¼ in. requires about 7,300 volts to jump, while to jump a gap of ½

in. requires about 9,200 volts. These values are for sharp metal points as terminals. Higher voltages, however, will be required if the points are made less sharp or blunt.

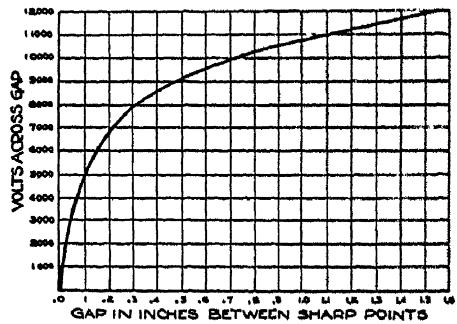


FIG. 102.—Curve showing voltages required to jump air gaps between sharp points.

83. The Safety Gap.—Because of the extremely high voltage induced in the secondary winding of an induction coil upon the interruption of the primary circuit, a gap of 5/16 to 3/8 in., known as the *safety gap*, is usually provided. This gap is either across the ends of the secondary winding in the coil itself or at some other point in the secondary circuit parallel to the gap at the spark-plug points. The purpose of this gap is to provide a by-pass for the high-voltage current in case a spark-plug wire should become disconnected, thereby causing the secondary circuit to be opened, or in case the spark-plug electrodes should become too far apart for the spark to jump when subjected to the high compression of the gas in the cylinder. In case such a break, offering greater resistance to the high-tension current than the resistance across the safety gap, should occur in the secondary circuit, the spark will jump the safety gap, thereby safeguarding the winding of the coil against excessive voltage which might puncture the insulation and cause short circuits.

84. Effect of Compression on Spark-gap Resistance.—As mentioned above, the resistance of an air gap increases with an increase in pressure. In actual practice the spark plugs are subjected to compression pressures varying from 60 to 85 lb. per square inch, which pressures are from four to six times the normal atmospheric pressure, which may be considered as 14.7

lb. per square inch at sea level. Thus, if the voltage is to be sufficient to jump a spark gap of 1/16 in. at five atmospheres, or approximately 75 lb. absolute pressure (absolute pressure is equal to gage pressure plus atmospheric pressure), it should be able to jump a gap at least five times as wide, or 5/16 in. under pressure of one atmosphere, or zero gage pressure.

It is evident that, if a spark plug shows good sparks when placed on top of the engine (in which case it is subjected to only atmospheric pressure), such a test does not prove that good sparks will be obtained under actual working conditions, since the resistance across the spark-plug electrodes increases almost in direct proportion to the rise in pressure

85. Igniting Power of a Spark.—It has been found by experience that a spark that will just jump a gap becomes more efficient in its heating or igniting power if the gap be reduced to one-half the maximum distance it will jump. By *igniting power* is meant the ability of the spark to produce sufficient heat for instantly raising the gaseous mixture to the kindling temperature at which ignition begins. Thus, if a coil will produce sparks that will just jump a 1/2-in. gap, the heat delivered in the sparks will be a maximum if the gap is reduced to 1/4 in. In the average ignition system the coil should provide a good hot spark at least 1/4 to 5/16 in. in length between fairly sharp points in order to give satisfactory ignition.

SECTION V

SPARK PLUGS

86. The Function of the Spark Plug.—The function of the spark plug is to provide inside the cylinder suitable electrodes between which the high-voltage current from an induction coil or magneto can jump to produce a spark for ignition purposes. Typical spark-plug construction is shown in Fig. 103. As will be noted, the two electrodes are insulated from each other, the center one being surrounded with insulating material, usually porcelain or mica, while the other is attached to the steel spark-plug-shell, which is grounded when screwed into the cylinder head.

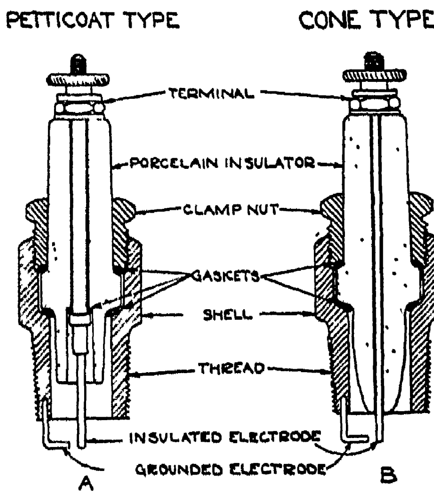


FIG. 103.—Typical spark-plug construction. (*A*) With petticoat-type porcelain. (*B*) With cone-type porcelain.

The conditions under which the spark-plug insulator must operate are severe. Not only must it withstand high electrical pressures of 5,000 to 7,000 volts or over with each ignition spark, but it must do this under conditions of high pressure and temperature each time the cylinder fires, which may be as many as 30 to 40 times per second with the engine running at high speed. With each explosion of the fuel charge, the pressure in the combustion chamber may rise momentarily to 300 and even 500 lb. per square inch. This pressure tends to blow the plug from the cylinder head. At the same time the heat of combustion, which in high-compression engines may reach a maximum temperature of 3,000 deg. F. or over, tends to burn and distort the electrodes, thus changing the spark-gap setting. In addition, the exposed

surfaces of the insulator tend to become over-heated and burned, with the result that the electrical conductivity of the insulator as a whole is materially increased. This is usually the cause of electrical leakage. Furthermore, the sudden changes in temperature cause unequal expansion and contraction of the insulator and shell parts, resulting in internal strains which tend to crack the insulator. It is, therefore, of highest importance that proper design and materials enter into the construction of the spark plug.

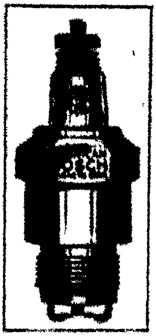
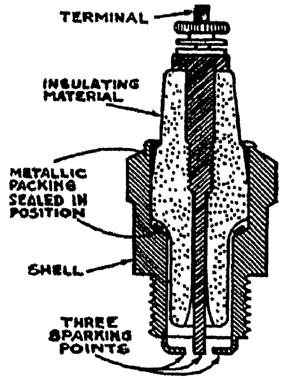
87. Typical Spark-plug Construction. As shown in Fig. 103, the principal parts of the spark plug are: (1) *the steel shell*, which is threaded for screwing it into the cylinder head, (2) the *insulating material*, for preventing passage of electrical current other than across the sparking points, and (3) the *electrodes*, or sparking points, which should form a gap of approximately $\frac{1}{32}$ in. or less, depending upon operating conditions. The best gap length will vary somewhat with the engine compression and the type of ignition system used, but, as a general rule, for automobile engines of normal compressions up to 80 lb., the gap should be adjusted to 0.025 in. for use with magneto ignition and 0.030 in. for use with battery ignition. The latter dimension is the thickness of three standard U. S. post cards.

Though many insulating materials have been used, the majority of the spark plugs on the market use porcelain as an insulator. These are generally provided with two shoulders, as shown in Fig. 103, by means of which the insulator with the center electrode is gripped in position in the shell. One of the shoulders bears against the shell seat, while the other bears against the packing-gland nut which screws into the upper portion of the shell. Both insulator seats are provided with a packing ring or gasket, usually of sheet copper and asbestos, to prevent undue mechanical strains that might cause cracking of the insulator, and to make a gas-tight seal between insulator and shell.

In some makes of plugs, for example, the Bosch, Fig. 104, and the Champion heavy-duty type, Fig. 111, the porcelain is held in place by the upper edge of the shell being crimped over so that it binds against the insulator—with a gasket between—thus dispensing with the gland nut. This construction simplifies the plug design somewhat, but prevents taking the plug apart in case it is desired either to clean or to replace a cracked porcelain. In the latter event, the only remedy is a new plug.

Practically all the plugs now on the market have steel shells; brass and other metals have been tried, but with poor success. Steel not only has high tensile strength, but its coefficient of expansion is practically the same as that

of the cylinder head. Furthermore, steel does not absorb heat as rapidly during the combustion period as do metals with higher heat conductivity,

(A) (B)

FIG. 101.—(A) The Bosch spark plug. (B) Sectional view showing insulator sealed permanently in place.

such as brass. This enables the plug to operate at a much lower average temperature, an important factor from the standpoint of cooling.

88. Effect of Spark-plug Installation on Its Performance.—One of the important factors in the operation of a spark plug is its proper installation and location in the engine cylinder head. The location of the spark plug is governed largely by the type of head used. Its location in the *I-head*, the *L-head*, and the *T-head* types of engines are usually as shown in Fig. 54. This figure also shows the typical arrangement of the valves and the shape of the combustion chamber, both of which have considerable influence on ignition.

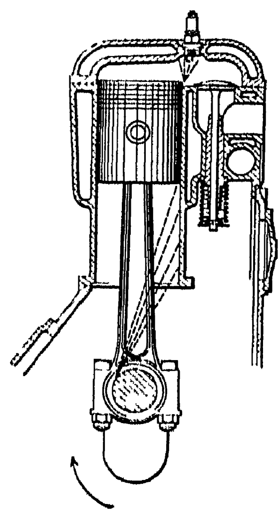
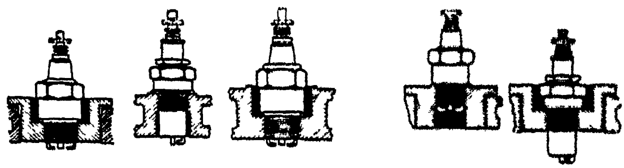


FIG. 105.—Unsatisfactory location of spark plug where it is subject to impingement of oil leaking past piston.

From the standpoint of speed of combustion, the ideal position of the plug would be such as to place the electrodes at the center of the combustion chamber, so as to equalize and shorten the distances the flame must travel from the plug to the distant corners of the combustion chamber. This location is impossible in many cases, however, on account of the shape of the cylinder head and the difficulty encountered in cooling the plug properly. The best practical arrangement seems to be for the shell to extend through the cylinder wall so that its inner edge is flush with the inner

surface of the combustion chamber, the electrodes only extending into the combustion space. Also, that the plug be located, if possible, so that it has the cooling effect of the intake gases during the intake stroke. Another point which should not be overlooked in plug location is that the plug does not fall in line with the edge of the cylinder bore, as in Fig. 105, since any spray of lubricating oil that may leak past the piston on the intake stroke would strike the plug and tend to foul it.

Since the cylinder-head wall varies in thickness in the different types of engines, spark-plug shells are made in several different lengths, so as to locate the sparking points in the proper relation to the gases in the combustion chamber. The plug should be of such length that, when the plug is screwed



CORRECT INCORRECT

(*A*) (*B*)

FIG. 106.—Correct and incorrect methods of installing spark plugs.

into place, the inner edge of the shell comes flush with the inside of the cylinder-head wall, as shown in Fig. 106*A*. If the shell extends beyond the inner edge of the cylinder, as in Fig. 106*B*, there will be danger of the plug becoming over-heated, causing preignition. On the other hand, if the plug does not extend entirely through the hole into which it screws, a pocket is formed for burned gases and there will be danger of misfiring, owing to the difficulty of the fresh gases reaching the spark-plug points. There will also be danger of the plug fouling (short-circuiting) badly by oil or carbon accumulation.

89. Spark-plug Dimensions.—In order to standardize the plugs so that they may be used in all engines, three principal types of screw threads for the shell which holds them in place in the cylinder head have been selected. These three styles are shown in Fig. 107. They are the ½-in. standard pipe thread, the ⅞-in., 18-thread S. A. E. standard, and the metric thread.

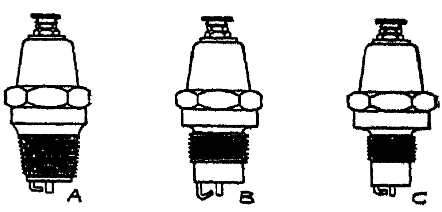


FIG 107.—Types of spark plug screw threads. (*A*) ½-in. taper thread. (*B*) ⅞-in., 18-thread, S. A. E. standard. (*C*) Metric thread.

The ½-in. pipe thread, which is the style used in the Ford and several other cars, has the advantage that, when screwed into the cylinder head,

it automatically seals itself and makes a tight fit. The disadvantage of this type of thread, however, is that, due to variations in the taping of the holes, the thread diameters may vary so that the shell and the electrodes may extend farther into certain cylinders than others.

In the 7/8-in., 18-thread plug, which is the one recommended by the S. A. E., the threaded portion is 7/8 in. in outside diameter and has a pitch of 18 threads per inch. The threaded portion does not taper; consequently, the plug will not seal itself and a gasket is required between the shell shoulder and engine cylinder head in order to seal the shell against gas leakage. The dimensions of the shell portion as standardized by the S. A. E. are as shown in Fig. 108. The upper part of the shell, where the wrench is applied for screwing into the cylinder, is made in two sizes, namely, 15/16 and 1 1/8 in. across flats, respectively, while the dimensions below the shoulder are identical for both sizes of shells. The threads and hole taps used should be made to comply with the following S. A. E. specifications:

"The outside diameter of the spark-plug threads shall be 0.8750 in. and the number of threads per inch shall be 18. The limits for the pitch diameter shall be 0.8389 in. maximum and 0.8348 in. minimum for the spark-plug threads and 0.8430 in. maximum and 0.8389 in. minimum for the tapped-hole threads."

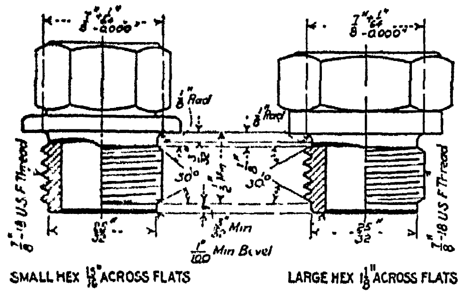


FIG. 108.—Dimensions of spark-plug shells —S. A. E. recommended practice.

With these dimensions, the spark plug can be screwed in by hand, using a wrench only for the final tightening. The nominal tap-drill diameter is 13/16 in., or 0.8125 in. The minimum diameter is 0.810 in. and the maximum 0.813 in.

The metric threaded plug is similar to the 7/8-in. S. A. E. standard, except that it is of smaller diameter, namely, about 11/16 in. This plug cools better, since the heat absorbed and, therefore, given off by any object is dependent upon its mass. Although this plug was designed originally for motor cycles and aircraft, it has been adopted for several prominent automobiles, for example, the Essex. Like the 7/8-in. S. A. E. standard plug, the metric plug requires a gasket to prevent gas leakage.

In the 1/2-in. pipe-thread plug, care should be taken that the shell is not screwed tightly into the cylinder when the engine is hot and the plug cold, as with the expansion of the plug upon heating or the contraction of the cylinder upon cooling it will be almost impossible to remove the plug by ordinary means. This trouble is not experienced in the straight-thread-type plug using a gasket.

90. Temperature Characteristics of Spark-plug Insulators.—The insulator used in spark-plug service must be of exceptionally

good quality in order to withstand the extremely high temperatures, pressures, and electrical strains. Many materials have been tested for this purpose, including glass, quartz, steatite, fused silica, mica, and porcelains, with various degrees of success. Commercially, porcelain of proper composition and design has many advantages from the standpoint of manufacture and service, although it is not considered as good an insulator at high temperatures as quartz and mica.

One of the outstanding obstacles in the use of any insulating material so far investigated is that its insulating ability, that is, its resistance to current leakage, decreases with an increase in temperature. This means that the insulator actually becomes a conductor to a certain degree at high temperatures, thus causing electrical leakage through the insulator and, consequently, decreasing the intensity of the spark at the points.

In automobile and aircraft service, spark-plug porcelain temperatures may run 400 to 500 deg. C. (approximately 750 to 1,000 deg. F.) while running under conditions of wide-open throttle and high compression. The quality of the porcelain, therefore, is of the utmost importance. Also the plug must be properly cooled, since it has been found that the conductivity of porcelain increases very rapidly with the increase in temperature; in fact, the conductivity increases according to the law of compound interest at a rate of about 2 per cent per degree Centigrade.

91. Composition of Porcelain Insulators. Porcelain insulators for spark plugs are made very much as china is made molded from special clays, chiefly kaolin and then fired at high temperatures to give a glazed surface. The kaolin, which forms the body of the porcelain, will not burn or melt together into a homogeneous material like glass when heated to a high temperature. It therefore requires a binder. Fluorspar is used for this purpose, since it will melt and run, and act as a cement, binding the particles of kaolin firmly together. The result is that, after the porcelain is fired, the fluorspar becomes a honeycombed mass surrounding and binding the kaolin particles together. Fluorspar is porous, however, so that if left in this state the porcelain would absorb, the moisture of gasoline, and eventually carbon would fill the pores. It is, therefore, given additional firing at the proper temperature until a glaze covers the entire surface. This renders it non-porous.

If, however, this glaze is destroyed through excessive temperature or by being scraped with a hard metallic tool in an effort

to remove carbon, the porcelain will be rendered porous and absorb carbon particles to such an extent that the current leakage may be sufficient to prevent ignition.

Many grades of porcelain have been produced for spark-plug service, but the one now considered the best commercially for automotive engines is a porcelain that was developed by the U. S. Bureau of Standards during the World War. Practically all the leading spark-plug manufacturers now furnish this porcelain in their best-quality plugs. It can be recognized by its cream color and the mark "775," the number of the original test specimen stamped on the upper end of the porcelain. It is produced in both the cone and petticoat designs.

92. Types of Porcelains.—As may be seen from Figs. 103*A* and *B*, the porcelain may be of two general shapes, namely, of the *cone* or of the *petticoat* type. Each has its particular advantages and disadvantages.

The Cone-type Porcelain.—In the cone-type porcelain, Fig. 103*B*, the advantages claimed are: (1) better cooling properties, and (2) more rigid construction of the center electrode. Porcelain is, in reality, a poor conductor of heat. However, with the section of the porcelain growing gradually larger as it proceeds away from the tip, the heat will be conducted to the shell readily through the increased cross-sectional area. Furthermore, since the tip is very short, it gives up its heat very quickly to the neighboring porcelain, thus rendering a temperature below that which would cause pre-ignition. Also, due to the increased cross-sectional area from the tip, the temperature of the porcelain becomes so low by the time the gasket is reached, that the difference in temperature between the portions just below and above the gasket are not very great, thus eliminating the possibility of unequal pressure and strains from unequal expansion of the porcelain and shell—a common cause of cracked porcelains. Other advantages in favor of the cone-type porcelain are the more rigid center-electrode construction, thereby preventing its warping and changing of spark-gap width, and the ease with which it may be cleaned in case it should become coated with carbon. However, the distance from the center electrode to the shell or ground is shorter than in the petticoat type, sometimes resulting in greater current leakage in case the cone should be covered with a carbon deposit.

Electrode Cement.—In the cone type of porcelain the center-electrode wire is usually cemented in place, while in the petticoat type it may not be. The quality of the cement used for this purpose is important, since it must hold the center-electrode wire rigid and at the same time maintain a gas-tight seal under the condition of high temperatures and unequal expansion stresses set up between the electrode wire and the porcelain. The cement used should not result in oxidation of the wire, thus causing it to break. A cement composed of silicate of soda and raw kaolin has been found to give the least trouble in this respect.

Where the cement holds the wire firmly in the porcelain, cracks often form in the porcelain when it is subjected to heat and to the strains set up due to the difference in the coefficients of thermal expansion of the wire and of the porcelain. In fact, breakage from this source is more common than from leaky gaskets. This applies particularly to low-grade porcelains. This fact may be considered a disadvantage in the cone-type plug. However, the "775" porcelain developed by the U. S. Bureau of Standards is believed to be of sufficient strength to withstand the stresses without cracking.

The Petticoat-type Porcelain.—In the petticoat-type porcelain the lower end takes the form of a skirt, as shown in Fig. 109*B*. The center electrode is not cemented in place as in the cone type, but is held in place between

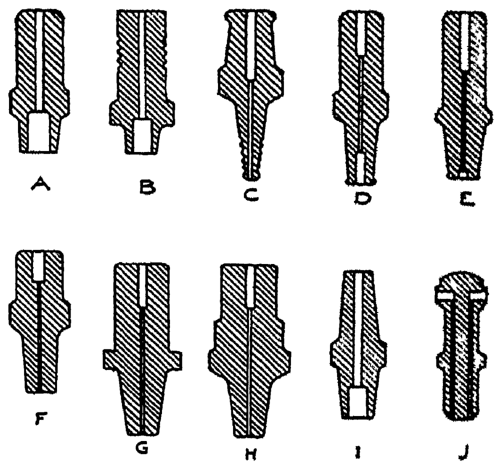


FIG. 109.—Types of spark-plug porcelain.

two gaskets, one at the terminal end and the other in a small seat at the electrode end. The electrode in this case can be made very tight and also removable without trouble, whereas the electrode in the cone type is permanently cemented in place.

The chief advantage claimed for the petticoat type of plug is the increased creepage distance between the center electrode and the ground, thereby reducing the possibility of short circuits through carbon deposit. The porcelain is harder to clean, however, and does not cool so readily as in the cone type. Furthermore, in case the skirt part should crack, due to unequal expansion or over-heating, it will usually drop down so as to ride on the grounded electrode and, being detached from the plug proper, will over-heat and cause preignition.

Both the cone and petticoat types of porcelain insulators are made in many shapes. Sometimes the surface is corrugated or *serrated* in the form of rings around the entire cone portion of the plug, as in Fig. 109*C*. The A-C plug, Fig. 110, is a good example of this. This construction lengthens

the creepage distance from the center electrode to the ground and helps prevent the carbon deposit from being continuous from the cone tip to the shoulder where the porcelain is seated. When the porcelain becomes hot any carbon which is on the high points of these ridges will be burned away, leaving valleys between them filled with carbon but not connected with each other, thus insulating one carbon ring from the next.

Sometimes the porcelain is serrated in the same manner above the shell—for example, the Champion plug, Fig. 111. The object in this case is to increase the creepage distance on the outside of the plug, thereby increasing the resistance and reducing the possibility of current leakage from the plug

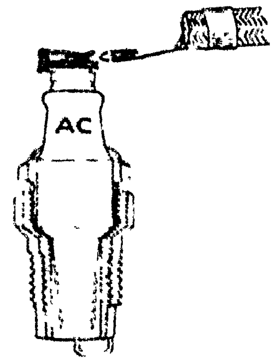


FIG. 110.—The A-C "1075" spark plug for Ford.

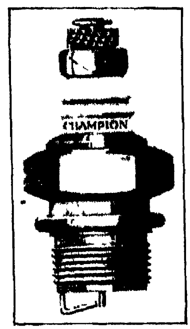


FIG. 111.—The Champion Heavy Duty spark plug

terminal to the ground. The disadvantage of this design is that, if the porcelain is not cleaned carefully, the valleys will remain filled with dirt and will thus help to cause short-circuiting of the plug.

Many spark-plug failures are caused by the porcelain being clamped too tight. When the porcelain is clamped between a gland nut and a shoulder in the shell, as in Fig. 103, great care must be exercised in drawing up the nut. If the nut is too tight, the proper expansion of the porcelain when subjected to the heat of combustion is prevented, and the porcelain will more than likely crack. Considerable experience is necessary in order to know just how tight the gland nut should be drawn to secure a proper gas-tight fit and yet permit proper expansion.

93. Mica Plugs.—Various types of mica plugs are shown in Fig. 112. As previously stated, mica will not conduct electricity at high temperatures as readily as porcelain. It, therefore, serves as a good insulator for high-temperature engines, such as the air-cooled and aircraft types. The natural form of mica is in thin laminations or sheets. Thus, its dielectric strength lies in its ability to withstand high electrical pressures applied per-

pendicular to its surface, or across the grain, while, on the other hand, if these pressures were applied along the direction of the grain, the high-voltage current is apt to creep along the surfaces of the laminated structure, thus breaking down the resistance. Mica also has the tendency of cracking readily when subjected to sharp bends. For spark-plug-insulating purposes, therefore, it has been found more successful in the form of washers pressed tightly together between two binding heads. The pressed washers are then turned and polished, giving the appearance of a solid material. Figures 112*A*, *B*, *E*, and *F* show plugs

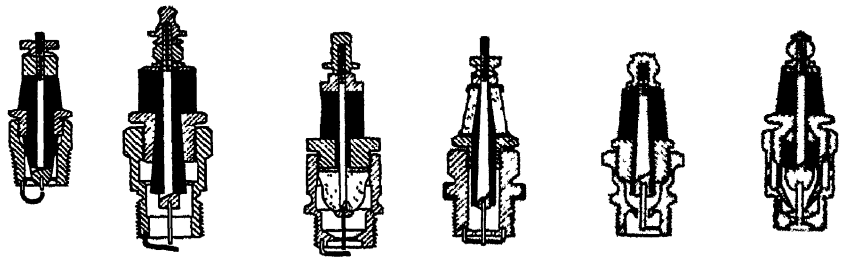


FIG. 112.—Types of mica spark plugs.

using mica as the only insulator, while Figs. 121*C* and *D* show combination insulators of mica and porcelain.

Even though the pressure between the washers is high, there is still a tendency for oil and gasoline to penetrate between the mica layers, where it carbonizes, due to the high temperature, thus reducing its insulating value. Therefore, to prevent current leakage between the center electrode and the ground, the center electrode is usually wrapped carefully with thin sheets of mica before the washers are assembled and properly supported so that it will not crack. A common design is to attach the center terminal to a tapered stem, the electrode being the larger end, as in *E*. By tightening the binding nut at the top, both the mica sheets around the stem and the washers are held tightly in place. This construction also tends to make the center electrode more rigid and gas-tight.

94. Advantages and Disadvantages of the Mica Plug.—The outstanding advantage of the mica plug over porcelain and other materials is its better insulating qualities at high temperatures. It also withstands heat particularly well up to the red temperature. Should it become heated much higher than to a red heat

however, it will blister and split into a large number of small flakes, presenting a roughened surface which will absorb carbon. This carbon is difficult to remove; in fact, about the only way it can be removed is by scraping with a sharp knife, a procedure more or less destructive to the mica. The mica plug is also more expensive to manufacture than most of the other types of plugs.

95. Closed-end Spark Plugs. In an attempt to improve the igniting characteristics of the plug, and as a protection to the insulator against heat and oil accumulation, many closed-end plugs have appeared on the market. In this type of plug the shell extends over the end of the plug, forming a chamber as in Fig. 113. The end virtually acts as a baffle plate to deflect the heat and oil from reaching the porcelain. In some cases the spark gap is formed between the insulated electrode and the shell, as shown, but this arrangement practically prevents adjustment of the gap length. Another feature claimed for this construction is that during ignition the gas which has entered the plug shell on the compression stroke will explode and fire past the electrode, keeping it clean and shooting a flame into the remaining combustible gas mixture, thereby accelerating flame propagation. This, however, is more theoretical than practical, since the plug chamber forms a pocket for burned gases. Difficulties also arise in maintaining a proper spark gap and from oil and carbon deposits forming within the shell chamber when the plug is installed in a horizontal position There is also a tendency for the shell end to over-heat in high-compression engines, causing preignition. This plug will be found to give best results if installed so as to operate in a vertical position.

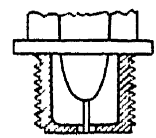


FIG. 113.—Section of typical closed end type spark plug shell.

96. Electrode Construction and Characteristics.—The shape and the composition of the electrodes play important parts in the performance of any spark plug. The electrodes should be made of some metal which will withstand both oxidation and the rapid burning away of the points due to the high temperatures created by the arc and combustion of the gases. They should also be as small as possible to facilitate cooling, yet large enough so that they will not burn away rapidly causing excessive wear of the sparking points—and consequent widening of the gap—and

have sufficient strength to withstand bending and warping in service.

Many materials have been used for electrodes, including nichrome wire, tungsten, nickel steel, platinum, molybdenum, and pure nickel. The electrode wire in most common use is a special nickel alloy consisting of approximately 97 per cent nickel, 1.5 per cent manganese, 0.8 per cent iron, and 0.4 per cent copper.

The shape of the electrode sparking points is also of considerable importance, since a higher voltage is required to produce a spark between blunt points or rounded surfaces than between sharp points. This difference in voltage may be as much as 30 per cent. It has also been found that much less voltage is required to cause a spark to jump from a sharp point or edge to a rounded or flat surface than from the surface to the sharp point. Thus, in plugs which have electrodes of different shapes or sizes, such as

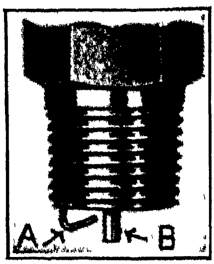


Fig. 114.—Spark plug with large and small electrodes.

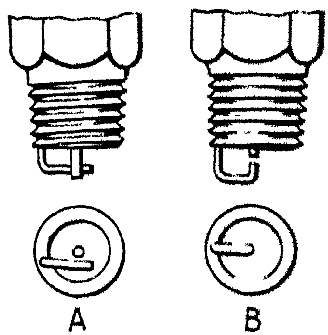


Fig. 115.—Desirable electrode construction.

in Fig. 114, there is a tendency for the plug to fire better when the small or sharp electrode is positive than when the large or blunt electrode is positive. This means that a better spark will be obtained when the grounded electrode *A* is of positive polarity.

In battery ignition, the polarity of the secondary current is usually constant unless a polarity-changing-type switch is used, in which event the polarity is reversed when the switch is reversed. In magneto ignition, however, it will be found that alternate distributor terminals are always positive, while the rest are always negative. Thus, in case plugs of the type shown in Fig. 114 are used in all cylinders, those having the grounded electrode positive will have the better ignition sparks, the others tending to misfire, particularly at low speeds under heavy compression.

It is evident from the above that the best results will be obtained if both electrode points are of the same shape, size, and degree of sharpness, and composed of the same high-grade material, for if both electrodes present the same kind of points for the spark to jump between the spark will always be of the same quality regardless of polarity. The two arrangements of

electrodes shown in Fig. 115 will meet these requirements and, consequently, are to be recommended. In *A*, the electrode wires are side by side, a very common design, while in *B* they are end to end. Various electrode designs are shown in Fig. 116

97. Multiple-pointed Plugs.—As shown in Fig. 116, some plugs have two or more points at which the spark might jump. Since the spark gaps are in parallel, the spark will naturally seek out the

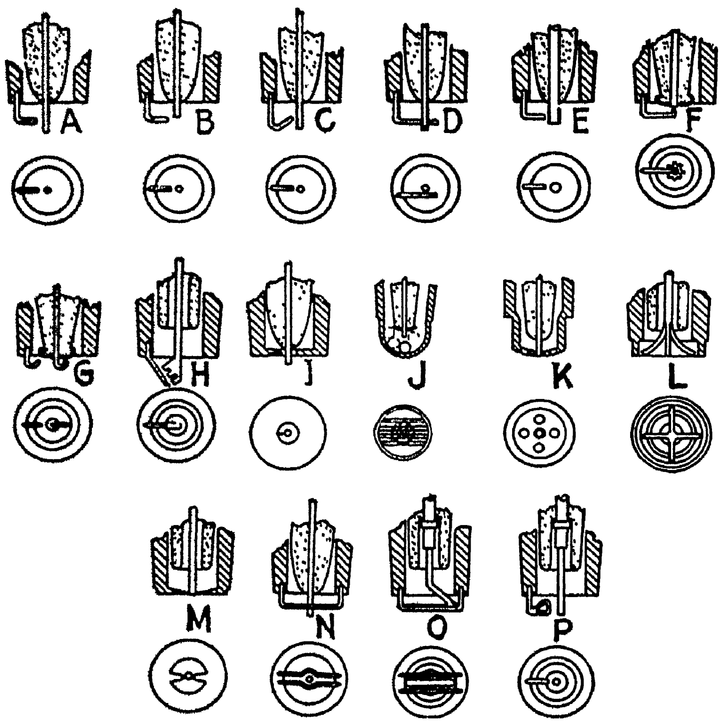


FIG. 116. Types of spark plug electrodes.

path of lowest resistance and jump that one gap only, instead of all the gaps, as may be supposed. The igniting power of the plug is, therefore, not increased by the additional points. The only important advantage of this arrangement is that, if all the points are set at the same gap, the proper gap distance can be maintained longer, due to the decreased wear of the points, thus requiring less frequent adjusting. Many mechanics and electricians either break off all but one set of points or bend them farther apart to avoid their fouling with oil and carbon.

98. Spark-gap Adjustment.—The proper spark gap to use differs with the engine compression and the make and type of ignition system. The usual spark-gap setting on automobile engines of normal compressions should be 0.020 to 0.025 in. for magneto ignition and 0.025 to 0.030 in. for battery ignition. If no gage is furnished with the ignition wrench (usually supplied with the equipment), a thickness gage consisting of two or three thicknesses of a standard U. S. post card may be used, since each card runs 0.010 in. in thickness. The total thickness may be varied by adding the proper number of ordinary cigarette papers, which are 0.001 in. in thickness, between the cards. Another gage which is roughly approximate is the thickness of a worn dime, which is slightly over 0.030 in. thick. In adjusting the gap width, the grounded electrode should be carefully bent, so that the gage will just slip between the points. When adjusting the gap, it is also advisable to make sure that the electrodes are rigidly anchored in the insulator and shell to insure a proper gap setting.

99. The Ionizing-type Plug.—In Figs. 116*F* and *G* are shown the electrode ends of two plugs which may be classed as the *ionizing* type. These represent the "Radd" and the "Twin Fire" plugs respectively. As will be seen, both plugs have a metal cap crimped over the tip of the porcelain and surrounding, but not touching, the center electrode. In fact this cap is not connected electrically to either the insulated or the grounded electrodes.

The Radd Plug.—In the Radd plug, Fig. 116*F*, the metal cap is used primarily to provide the ionizing feature. In this plug the metal cap is not in series with a second gap, but is provided with several V-shaped projections which nearly (but do not) touch the center electrode. This electrode has a spark gap direct to the grounded electrode as shown. When the central electrode becomes charged to a high voltage from the coil or magneto, a small spark will jump across the small gap (approximately 1/64 in.) from the center electrode to the cap, sending out wireless waves, as explained above, and ionizing the main gap. This ionization reduces the resistance of the main gap as much as 30 per cent or more, with the result that proportionately less voltage is required to jump it.

This gives the plug distinct advantages over the usual plug for the following reasons: (1) A better spark will be obtained at lower voltages, which is a particular advantage when cranking on a magneto or a weak battery. (2) The plug will fire under higher compressions with the same gap setting and secondary voltages. (3) The gap may be set wider than in the ordinary

plug, thus reducing the possibility of fouling with oil or carbon. (4) The plug will give better performance than most plugs in cylinders troubled with excessive lubrication, since, due to the decreased gap resistance, the plug will usually fire in spite of oil and carbon which may tend to short-circuit it. The principal disadvantage of this plug is its tendency to cause pre-ignition in high-compression engines, due to the improper cooling of the tip of the porcelain and cap It has, therefore, not been produced for motorcycle and aircraft service

The Twin Fire Plug.—The primary object of the Twin Fire plug, Fig. 116G, was to provide two spark gaps in series, thus presenting two sparks for igniting the gas. One gap is between the center electrode and the cap and the other between the cap and the grounded electrode Also, it was aimed to have at least one effective spark in case the other gap should become fouled. Naturally, since both gaps are in series, each gap should be somewhat smaller than normal, as both gaps are subjected to the same compression and the high-tension voltage must break down the added resistances of both gaps

There is one interesting feature about this plug, namely, the *ionizing* of the spark gaps, which makes it fire better than one would expect since the sum of both gaps is greater than the normal setting The metal cap which surrounds the center electrode (close to it but without electrical connection) is situated between the center electrode and the ground and acts as a condenser, so that, when the electrodes are charged to a high voltage (an instant prior to the main secondary discharge) a small spark jumps between the cap and electrode. This small spark sets up wireless (radio) waves which cross the other gap, thus partially ionizing it and thereby reducing its resistance. This means that less voltage is required to jump the two gaps, so that the total striking distance of the gaps in series is actually reduced in effect to that of a smaller gap.

100. Special Spark Plugs for Two-point Ignition.—In engines having a spread-out combustion chamber, such as in the T-head type engine, Fig. 54, it has been found that, if ignition is produced at distant points in the combustion chamber at the same instant, say, in two plugs, one over the intake valve and the other over the exhaust valve, the period of flame propagation may be reduced one-half, thus requiring approximately one-half the spark advance which would be required if the ignition occurred at one plug only. There will also be a material increase in horsepower and in fuel economy. This scheme of setting fire to the fuel charge at two points, simultaneously, is known as "two-point ignition."

Two-point ignition may be accomplished best by having the two spark plugs operate in series from the same high-tension source. A common plan is to use one special plug known as a "series" plug, in which both

electrodes are insulated and connected in series with a standard type of plug as shown in Fig. 117. A common plug used for this purpose is the "Su-Dig" plug shown in Fig. 118. The plug is merely connected in the high-tension circuit between the ignition distributor and the standard plug. Both electrodes of the series plug are insulated, so that the high-tension current from the distributor must pass through this plug, thence across the gap of the standard plug before it can return through the ground to its source. Since the gaps in the two plugs are both subjected to the same compression pressures, the points should be set slightly closer than normal, say 0.020 in., otherwise the added resistance of the two gaps in series may be sufficient to cause misfiring under heavy compression.

Two-point ignition, using two standard plugs, may also be accomplished by connecting the plugs to the opposite ends of the same high tension winding by a special double distributor. Another plan is to operate the

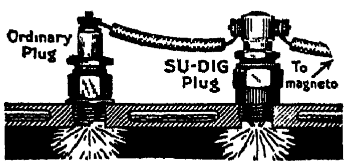


FIG. 117.—Spark plug arrangement for series firing.

FIG. 118.—Typical series type spark plug. (SU DIG.)

two plugs from independent high-tension sources synchronized to spark at the same instant. However, true synchronizing of the spark is difficult to obtain by the latter method, so that, from the standpoint of accuracy in timing, either of the two series methods described is to be preferred.

101. Spark Intensifiers.—Auxiliary spark gaps, commonly termed *spark intensifiers*, are often put in series with the regular plugs of an engine in an attempt to improve the igniting power of the plug. An auxiliary gap consists of a small gap of approximately $\frac{1}{32}$ in. placed in series with the spark gap of the plug, but so located, either inside or outside the plug, that it is subjected to only atmospheric pressure. Figure 119 shows typical spark-plug construction with an auxiliary spark (or intensifier) incorporated. In many instances the intensifier is made into a glass-protected self-contained unit (resembling a fuse) with two terminals, one for connecting to the spark-plug wire, the other to the plug terminal.

The principle of the intensifier is as follows:

In case no auxiliary gap is used and the plug terminal is connected directly to the high-tension winding of the coil through a wipe-type distributor, and in case the plug points should be partially short-circuited either by carbon deposits on the porcelain, or by a drop of oil or carbon bridging the points, the high-tension circuit will be partially short-circuited through the fouled plug. Normally, when the plug is not fouled, the voltage of the secondary circuit will build up until it can break down the spark-gap resistance and the discharge of current or arc across the points will be of sufficient heat intensity to ignite the fuel charge. With the plug badly fouled, however, current will begin to flow through the secondary circuit as soon as the voltage begins to build up in the circuit, the current passing through the carbon deposit. The result is that the induced energy in the secondary winding dissipates itself through the fouled plug without producing a spark across the points sufficient to create ignition. If an auxiliary gap be placed in series with a plug which is in this badly fouled condition, it will have the effect of a dam, since, because of its added resistance, amounting to approximately a 20 per cent increase, the circuit is not completed and, consequently, no current will flow in the spark-plug circuit until the voltage rises to a value sufficient to break down the added resistance of both the auxiliary and spark-plug gaps. It will then cause so much energy to be discharged through the plug that an arc will be set up across the main-gap points and of sufficient heat to create ignition in spite of the short-circuiting effect of the carbon. Furthermore, if the plug should be fouled by a drop of oil bridging the points, the sudden secondary discharge will produce sufficient heat to vaporize and burn the oil from the points.

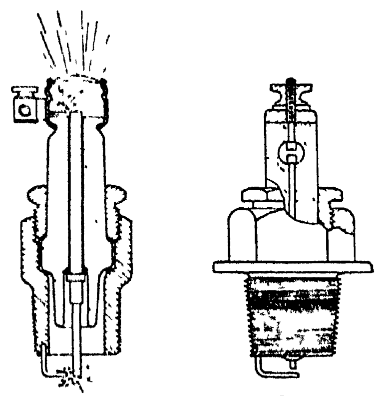


FIG. 119.—Typical spark plug construction with auxiliary spark gap (or intensifier) incorporated.

However, after the plug has once freed itself of carbon and oil deposits by the regular firing of the cylinder, the auxiliary gap has no special advantage. In fact, its use may be considered a disadvantage, since the secondary circuit must necessarily operate at an abnormally high voltage, involving an extra strain on the coil winding and condenser, and with no appreciable improvement in ignition. The same intensifier effect is obtained in many modern battery and magneto ignition systems by the use of the gap-type distributor. In general, the auxiliary spark gap or spark intensifier is usually quite unnecessary. It certainly is not a cure for all ignition ailments, as is often claimed.

102. Spark-plug Cable Terminals.—Several types of terminals are used for connecting the high-tension cable to the spark plug.

As the spark-plug high-tension wiring is usually flexible, supported only at intervals, the vibration of the engine is apt to cause them to become loose from the plugs. For this reason, special terminals which clip or spring onto the spark-plug terminal are often used. Figure 120 illustrates several types of these terminal connectors, the one shown in *D* being the most commonly used. Each type has certain special features. Some will prevent the cable from being pulled off from the spark plug entirely, while others will resist only a certain tension before pulling loose. For example, *B* and *C* hook over the spark-plug tip and cannot be pulled off, but must either have the spring compressed or be pushed in the opposite direction to the normal wire tension in order to relieve them, whereas *A* and *D* will give way when the resistance of the spring action of the clip is overcome by the pull. In the same manner the ball-type terminal, which snaps over the round tip of the plug, will relieve its hold if sufficient tension is placed upon the cable.

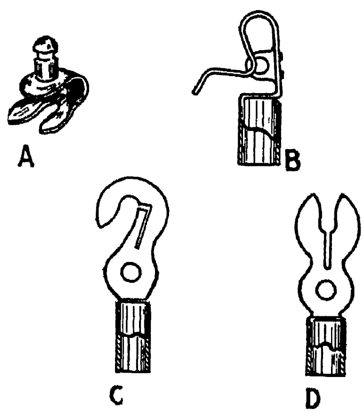


FIG. 120 —Types of spark plug cable terminals.

103. Testing Spark Plugs. Probably the most satisfactory way of testing a spark plug is to test its performance under pressures as high or higher than those in which it must operate in service. The best way to accomplish this is to use a special compression chamber, Fig. 121*A*, into which the plug can be screwed and the pressure raised to the desired amount by an air pump. At *B* is shown the compression chamber and pump mounted with a small air tank by means of which the pressure may be regulated.

To test the plug for gas leakage past the insulator, simply immerse the compression chamber and plug in water and watch for air bubbles. If the central electrode leaks, bubbles will appear at the terminal. If the insulator gaskets leak, bubbles illw form at the gland nut, and, if the threads leak, bubbles

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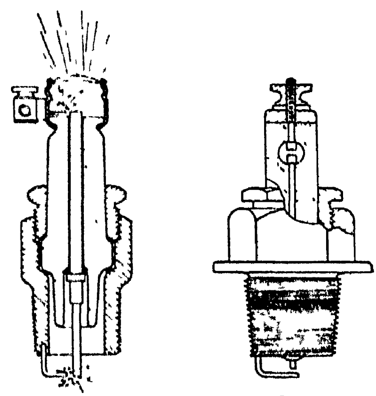

FIG. 119.—Typical spark plug construction with auxiliary spark gap (or intensifier) incorporated.

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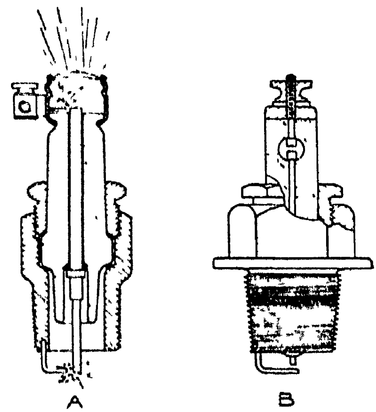

FIG. 110.—Typical spark plug construction with auxiliary spark gap (or intensifier) incorporated.

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is mounted either on the instrument board, or on the steering column within convenient reach of the driver.

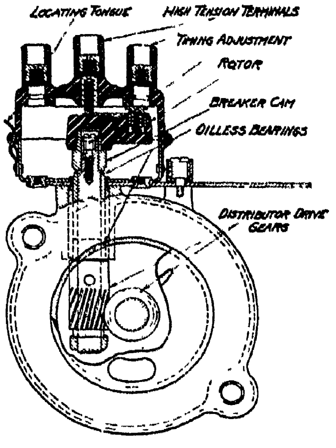


FIG. 123.—End view of Delco generator with battery ignition unit driven from armature shaft.

A wiring diagram of a typical automobile battery ignition system for a four-cylinder engine is shown in Fig. 124. This diagram shows a *closed-circuit* type of breaker in which the breaker contact points are normally closed. Both the distributor and the breaker are operated by a single vertical shaft, the distributor arm or block being carried on the upper end of this shaft immediately above the cam which actuates the breaker points.

Requirements of Battery Ignition Systems.—In all four-, six-, eight-, or twelve-cylinder four-stroke-cycle engines such as are used in automobiles, trucks, tractors, and aircraft, all the engine

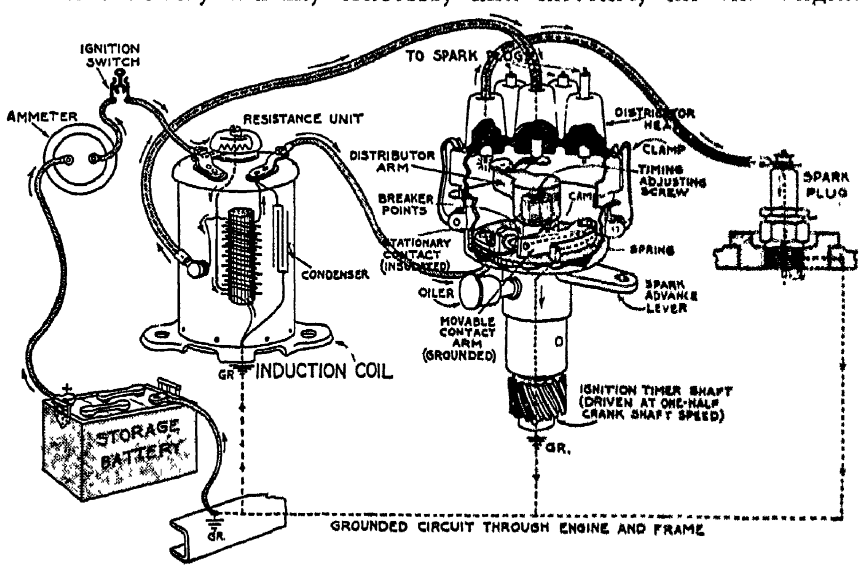


FIG. 124.—Construction and circuits of typical battery ignition system.

cylinders must fire in two revolutions of the crankshaft. This means that during each revolution of the engine crankshaft

half of the total number of cylinders must receive an ignition spark. Thus, the ignition system must deliver to the engine cylinders two, three, four, and six sparks, respectively, during each revolution of the crankshaft. In the usual four-, six-, and eight-cylinder engines, ignition is provided by using a four-, six-, or eight-lobed cam for interrupting the primary circuit, and a high-tension distributor—with as many equally spaced terminals as there are cylinders—for directing the secondary current to the various plugs in their proper firing order. In some eight- and twelve-cylinder V-type engines a separate breaker and distributor unit is employed for each cylinder block. In others the firing angles are unequal, requiring specially constructed breakers and distributors to provide proper ignition.

105. Ignition-breaker Requirements and Characteristics.—The function of the breaker is to close and open the primary ignition circuit at the proper time in order to provide suitable ignition sparks for the engine. If the breaker is of the open-circuit type, such as the Atwater-Kent, type K-2, Fig. 93, the period of breaker contact is extremely short and fairly constant regardless of engine speed. This means that a very fast coil must be used, otherwise the contacts may open before the primary current has risen in the circuit to the proper value to give an effective spark when the contacts open. In such breakers, if the adjustment of the contact opening, spring tension, etc. is satisfactory for low-speed service, it may usually be assumed that it will work satisfactorily at the higher speeds, since the period of contact closure (and, consequently, the time available for the coil to magnetize) is not dependent upon engine speed, but, instead, upon the contact opening and spring adjustment.

This action, however, does not apply to breakers of the closed-circuit types in which the contacts are held normally closed by spring tension. A typical battery ignition breaker of the Remy type is shown in Fig. 125. A study of Fig. 126 shows that the period of contact is from the time one cam lobe passes the contact arm buffer, allowing the contacts to close, until the next lobe strikes the buffer, causing the contacts to open. From a study of this figure it is also evident that the shape of the cam lobe and the width of the *follower* or *buffer* on the contact arm are the impor-

tant factors which govern the period of contact closure, as well as the speed at which the contacts open. In Fig. 126*A* the cam

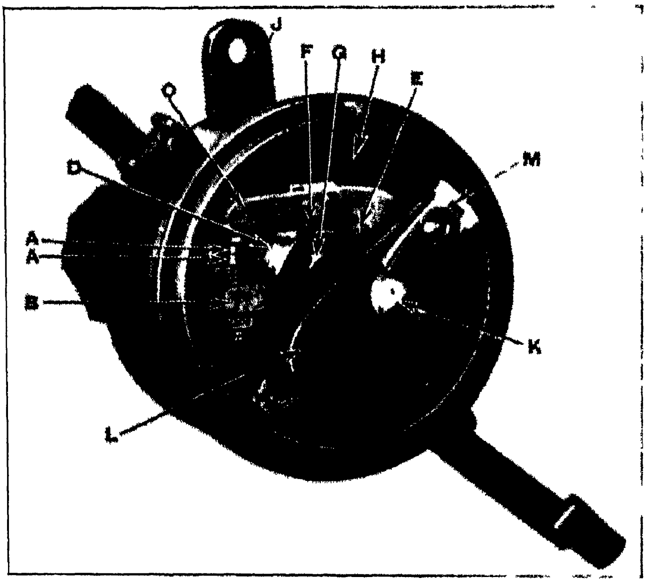


FIG. 125—Typical closed-circuit type battery ignition breaker (Remy) *A*, contact points, *B*, insulated contact block; *C*, pivoted contact arm; *D*, cam, *E*, spring; *F*, fibre buffer, *G*, cam lock nut; *H*, breaker plate, *J*, manual spark advance arm; *K*, distributor contact and spring, *L*, distributor arm, *M*, distributor segment.

lobes are fairly sharp, permitting a large angle of contact closure and giving a quick break at the moment of contact opening.

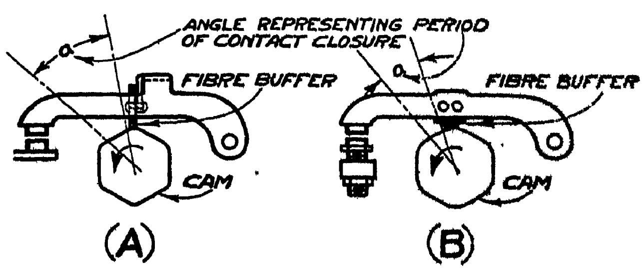


FIG. 126.—Types of cams, showing effect of cam design and fibre buffer width upon period of contact closure. (*A*) Sharp cornered cam giving long period of contact. (*B*) Tangential type cam giving short period of contact.

In Fig. 126*B* the lobes are more rounded, or *tangential*. This causes the contacts to open with less abruptness than in *A* and

reduces the angle of contact closure. Each type of cam has its peculiar characteristics. The one shown in Fig. 126*A* is better adapted to engines which operate at high speed, since more time is allowed the coil to "build up." At low speed, however, the current consumption is higher and the cam lobe and buffer (particularly the latter) wears faster, due to the scraping effect. On the other hand, the cam shown at *B* has better wearing qualities and a lower current consumption, since the angle of contact closure is smaller; but it is not as satisfactory for high-speed service.

In practice, the various ignition manufacturers strive to produce a breaker that will give good all-round service, which means that the usual cam used is a compromise between the two shown one which allows the contacts to be closed approximately 50 per cent of the time. This design usually avoids excessive waste of current at low speed yet permits an efficient spark at high speed. In this respect, the performance of the breaker is aided to some extent by the proper functioning of the resistance unit as explained in Art. 109.

Importance of Cam Accuracy.—Since the spark occurs in the cylinder at the instant the breaker points open, it is essential that the lobes of the cam be ground and spaced very accurately, so that the spark will occur in each cylinder at exactly the same point in the revolution. The spacing of the cam lobes is of particular importance, since the cam usually revolves at one-half crankshaft speed and an error of, say, 5 deg. in breaker opening by one of the cam lobes means that the spark will be 10 deg early or late in the cylinder.

106. The Breaker Contact Points.—Although a condenser is used to prevent sparking at the breaker points, still the nature of the metal used in the contact points has a great deal to do with their performance as well as with the quality of the spark produced. Ordinary metals, such as iron, copper, brass, or zinc, cannot be used for contact points because they vaporize readily at low temperatures, thus increasing the tendency to arc and thereby spoiling the speed of the break. This will, in turn, cause rapid burning and pitting of the points due to the heat of the arcing and at the same time cause a feeble secondary spark.

For these reasons, platinum and tungsten, both of which have extremely high melting points, have been generally adopted as

contact metals. Platinum, when alloyed with 20 per cent iridium to give hardness, is accepted as the best all-round metal yet discovered for ignition contact service, but on account of its rareness and extremely high cost its use is confined chiefly to high-tension magnetos where the service is most severe. On the other hand, tungsten has been universally accepted as the best commercial metal for battery ignition service. A typical battery ignition breaker arm showing a tungsten contact mounted in place is shown in Fig. 127.

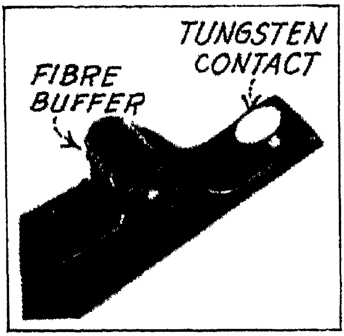


FIG. 127.—Tungsten contact mounted in contact arm (Delco).

Tungsten.—Tungsten is a most interesting metal. It is extremely hard and withstands extremely high temperatures. It is produced from an ore called "wolframite," mined chiefly in Korea. The tungsten is extracted from this ore by chemical processes and is reduced to a fine metallic powder. Then, under a hydraulic pressure of several hundred tons, the tungsten powder is formed into bars which are sintered (freed of impurities) by passing a heavy electric current through them. Each bar is then heated and swaged repeatedly until it is brought down to the required size for cutting into contact points.

The complete extracting of impurities from the tungsten is a most important factor, as it controls the ability of the point to stand up in service. Not only must the tungsten be pure, but it must be finely worked as well. The difference between good- and poor-quality points is clearly shown in the two magnified views shown in Figs. 128*A* and *B*. *A* shows the texture of a high-grade tungsten contact point in which pure tungsten, finely worked,

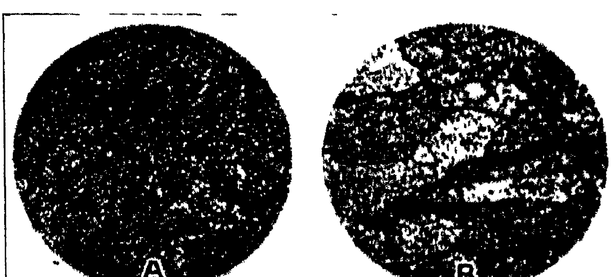


FIG. 128.—Magnified views of good and poor quality tungsten contacts. (*A*) Good quality, showing pure tungsten finely worked. (*B*) Poor quality tungsten, showing poor grain structure and the presence of impurities.

has been used, while *B* shows a poor-quality point in which there is poor grain structure and impurities are present. In the replacing of contact points it is, therefore, important that much care be taken to use only points of the best quality. This can usually be done by selecting those furnished or recommended by the ignition-equipment manufacturer and termed by him as genuine parts.

In practice, the contact points are usually mounted as shown in Fig. 125. One is mounted (riveted) in the end of the contact arm, as shown in Fig 127; the other contact is in the form of a steel screw on the end of which the tungsten point is welded. The screw is adjustable and is locked in position by a locknut, as in Fig. 125

Contact Opening. The normal maximum contact opening in the closed-circuit type of breaker is 0.015 to 0 022 in., the exact opening to use depending somewhat upon the style of cam, maximum engine compression, speeds, etc. The spring tension holding the contacts closed should be usually 1 to $1\frac{1}{4}$ lb at the moment the contacts start to open. A greater tension should be avoided in order to reduce to a minimum the hammering action of the contacts at the time of closure. The tension, however, should be sufficient to insure the proper return of the arm and the closure of the contacts at high speed.

107. The Distributor.—The function of the distributor is to direct the secondary current from the induction coil to the various spark plugs of a multi-cylinder engine in their proper order of firing. The distributor head or cap, Fig. 124, has a center terminal which connects with the secondary terminal of the induction coil, and has as many metal segments or terminals equally spaced around it as there are cylinders to fire. The head is usually molded of a high-resistance insulating material, such as Bakelite or Condensite. These materials are moisture-proof and possess high insulating properties even under excessive heat. The terminals are of metal alloy molded in position, terminating on the under side either in the form of a button-like segment flush with the surface or in the form of a pin.

Mounted on the upper end of the same shaft that operates the breaker is the *distributor arm* or *rotor*, which revolves with the cam. It is so timed that, shortly before the breaker opens to produce a spark, the conducting segment of the arm or rotor moves into such a position as to connect the center distributor terminal to the terminal that is wired to the plug to fire. The distributor, therefore, may be considered as a revolving switch located in the secondary circuit, and automatically connecting the high-tension wire from the coil to the proper spark plug at

the proper time. The distributing segment must of necessity be well insulated to prevent grounding of the high-tension current; consequently, it is usually molded into a block of insulating material, such as Bakelite or Condensite, similar to that used in the distributor cap. The distributor arm is usually designed to fit down over the end of the timer shaft in one position only. This prevents its installation in a position which would throw it out of time with the breaker. The distributor head is also made to fit in one position only.

Types of Distributors.—There are two types of distributors, the *gap* type and the *contact* type, according to the method used in completing the circuit between the distributing arm and the distributor-head terminals. In the gap type, Fig. 124, the segment of the distributor arm does not make actual contact but, instead, simply passes close to the spark-plug wire terminal extensions so that a small gap (approximately $\frac{1}{64}$ in.) is present. The spark must then jump this small gap in addition to that of the plug and, as they are in series, the voltage required to overcome the added resistances must be slightly greater than for the plug alone. Good examples of the gap construction are found in the Remy, Atwater-Kent, and Connecticut distributors.

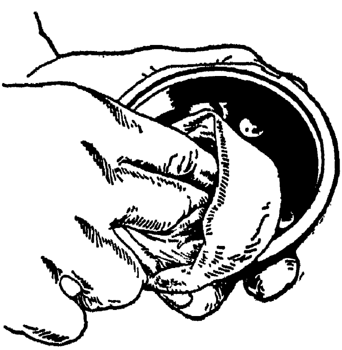


FIG. 129.—Method of cleaning distributor head.

In the contact-type distributor, good examples of which are found in the Delco, Fig. 123, North East, and Westinghouse equipment, the end of the distributing arm makes rubbing contact with the segments in the head either by a metal button or by a carbon brush. In this type the rubbing surface is usually composed of a hard-rubber track with the segments molded in place and flush with the inner surface. Hard rubber is used for the track instead of Bakelite, as the latter has a tendency to form surface cracks as the friction of the button or brush causes the track to wear rough.

The distributor head is usually held in place by two spring clips which fit properly only when the head is in its proper position. Thus, the head can be easily removed to make the distributing arm and breaker mechanism readily accessible for inspection and adjustment. On systems where the distributor makes a wiping contact, it is advisable to remove the cap about once a month, or each 1,000 miles of travel, and wipe the track clean, using a rag slightly moistened with oil or vaseline as in Fig. 129. This will keep it polished and prevent the rotor button from sticking and cutting the track.

108. The Resistance Unit.—The resistance unit which is widely used in automobile battery ignition systems plays a very

important part in the operation of the system. It serves both as a protective device and to regulate the quality of spark at high and low speeds.

The resistance unit consists usually of a number of turns of resistance wire of either German silver or a special nickel-chrome alloy, commonly known as "nichrome," connected in the primary ignition circuit. The important characteristic of either kind of wire is that its resistance increases as it is heated the change in resistance being used to control the current flowing in the circuit. Nichrome wire is more generally used, since up to a dull cherry-red heat (approximately 1200 to 1400 deg. F.) the increase in its resistance is practically in direct proportion to its increase in temperature. (These temperatures may be considered the highest at which the unit will normally operate.)

As a protective device, the resistance unit functions as follows: In case the ignition switch is left in the "On" position with the engine not running and the breaker contacts closed, the battery is free to discharge through the primary circuit. This causes the resistance wire to heat up immediately, causing a sudden rise in the circuit resistance. This, in turn, will cause the current discharge from the battery through the primary winding to decrease sufficiently to protect the coil against damage from over-heating and the battery against rapid discharge. On the other hand, should the battery become disconnected from the circuit while the engine is running, as may occur due to a corroded battery terminal or a loose connection in the charging circuit, thereby destroying generator regulation and causing the generated voltage to become excessive, the resistance unit may act as a fuse, thus opening the primary ignition circuit and preventing more serious damage to the electrical system which would be caused by the continued operation of the engine.

109. Effect of the Resistance Unit upon the Ignition Spark.—Since the resistance unit is connected in the primary ignition circuit in series with the breaker, it is evident that the resistance of the primary circuit and, consequently, the amount of current flowing in the circuit during breaker contact, depends largely on the temperature of the resistance element. At low engine speeds, the duration of breaker contact is longer than at high speed, with the effect that a greater average current tends to

flow through the primary circuit. This causes the resistance unit to rise in temperature, accompanied by a proportionate rise in resistance. On the other hand, at high engine speeds the period of breaker contact is proportionately shorter, resulting in a decreased average current flowing in the primary circuit and causing the resistance unit to operate at lower temperatures and with less resistance than at low speeds. This change in resistance, due to the variation in temperature of the resistance unit, automatically decreases the average current flowing at the lower speeds, while at high speeds it tends to allow more current to flow, thus apparently improving the quality of spark as the speed increases.

In closed-circuit breakers the period of time which the primary current has for magnetizing the core will, of course, decrease in proportion to the increase in engine speed; consequently, since it requires a certain length of time for the core to magnetize fully (usually 0.001 to 0.02 sec., depending upon the design and construction of the coil), there is a tendency at high speed for the breaker to interrupt the primary current before the core is fully magnetized, thus decreasing the intensity of the secondary spark. This is counteracted to a certain extent by the decrease in temperature and the resistance of the resistance unit at high speeds, since a decrease in resistance will permit a larger momentary flow of current through the primary winding during the brief period in which the breaker points are closed. By thus controlling the primary current, the intensity of the secondary voltage is caused to be more nearly uniform at the different speeds of the engine.

The resistance unit also assists the coil to produce a hotter spark when the battery voltage is low, since at that time the current is correspondingly low, and the temperature and the resistance of the unit do not increase greatly.

Caution!—To relieve an emergency in case the resistance unit should be burned out or accidentally broken, the terminals to which it connects may be temporarily short-circuited with a piece of wire. Should this be done, however, *the resistance unit must be replaced with another of the proper kind as soon as possible*, as continued operation without it will result in serious burning of the breaker contact points and may cause injury to the coil and condenser.

110. Manual and Automatic Spark Advance.—In the case of practically all battery ignition systems, the time of the spark relative to crank and piston position can be varied with the engine

running either by shifting the breaker mechanism around the cam, or by shifting the cam with respect to the breaker mechanism. If the breaker arm is shifted in the direction of cam rotation, the contacts will open later with respect to the crank position and the spark will be retarded. On the other hand, if the breaker arm is shifted against the direction of cam rotation, the contacts will open earlier with respect to the crank position and the spark will be advanced. In case the time of the spark is varied by shifting the cam, the reverse will be true, that is, shifting the cam in the direction of normal rotation will cause the contacts to open earlier and thereby advance the spark, while shifting the cam against its normal rotation will cause the contacts to open later, thus retarding the spark.

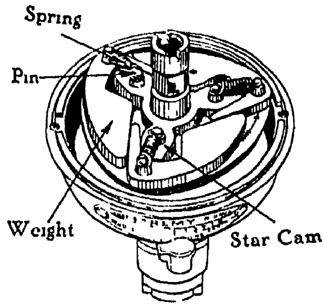


FIG 130 Automatic spark advance mechanism for Remy Battery ignition breaker

The advancing and retarding of the spark may be performed either manually by the driver through a spark-control lever on the steering wheel that is linked up with the breaker housing, or automatically by a governor device incorporated with the breaker unit and driven by the engine. In the latter method, the spark is advanced and retarded automatically with changes in engine speed, while manual advance requires certain skill and continuous attention on the part of the driver as the engine speed varies. The purpose of the automatic spark advance is to relieve the driver of the responsibility and uncertainty of gaging correctly the proper position for setting the spark-control lever during normal driving speeds. Its use generally results in greater fuel economy and better operation of the engine at normal driving speeds.

The Remy Automatic Spark-advance Mechanism.—The type of automatic spark-advance mechanism used in the Remy ignition unit is shown in Fig. 130.

As may be seen, the automatic advance mechanism is simple in construction. Three centrifugal weights advance the cam as the speed increases. The camshaft which carries the breaker cam also carries a star-shaped punching called a star cam. The tangs of the weights rest against this cam. As the weights fly outward, due to centrifugal force with increase

in speed, the star cam is shifted against the tension of the three springs holding it, and the breaker cam is advanced. Then, when the speed decreases, the weights return gradually to their slow-speed position, due to the spring tension, and the cam is automatically retarded.

The characteristics and the calibration of the automatic spark advance are mechanically fixed by the shape of the curve on the cam star. From normal retard position the weights move easily and the spark starts to advance. The degree of spark advance will then be controlled by the engine speed and the tension of the weight springs, assuming, of course, that the movable parts all move freely on their pivots. In addition to the automatic advance feature, the Remy breaker is also equipped with a manual advance to enable the driver to control the time of spark at abnormal speeds. The hand advance need be used only when the engine is run with wide-open throttle at very low speeds, and again at maximum speeds.

Other types of automatic spark-advance mechanisms are described later in this section, in connection with the system in which each is used.

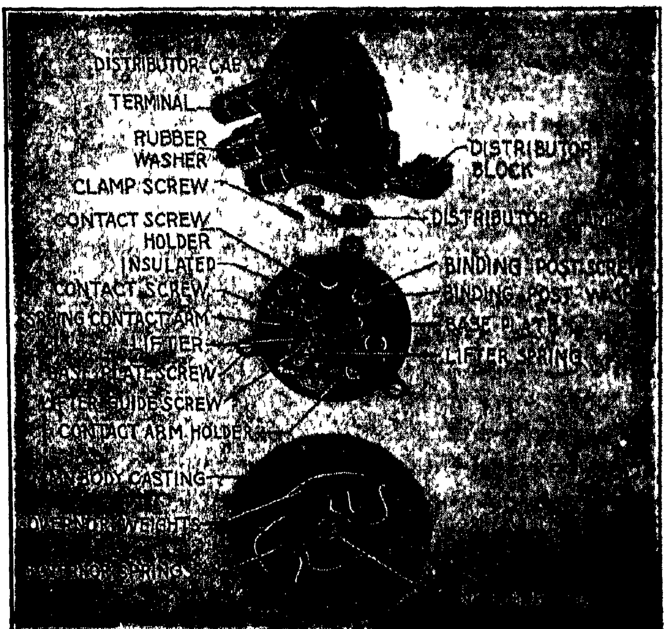


FIG. 131.—Construction of Atwater-Kent open-circuit type breaker, type K-2.

111. The Atwater-Kent Ignition System—Open-circuit Type. The Atwater-Kent battery ignition system is made in two principal types, the *open-circuit* type, in which the interrupter points are normally open, and the *closed-circuit* type, in which the interrupter points are normally closed. The open-circuit

type system was developed primarily for use with dry cells, while the closed-circuit type was developed for use with a storage battery and generator.

Construction of Breaker Mechanism, Type K-2—A typical model of the Atwater-Kent open-circuit type of system is the type K-2, which has been widely used on the Hupmobile, Peerless, King, Franklin, and Chalmers cars. Several of these cars, however, have recently changed to the closed-circuit-type Atwater-Kent system commonly known as type CC or RA.

The principal parts of the type K-2 system are the ignition breaker and distributor unit, or *unisparker*, as shown in Fig 131, and a non-vibrating under-hood type of induction coil. The switch may be a simple key switch combined with the lighting switch of the car, or it may be a special polarity-changing type mounted independent of the lighting switch, the function of which is to reverse the direction of the primary current through the interrupter points each time the switch is turned on

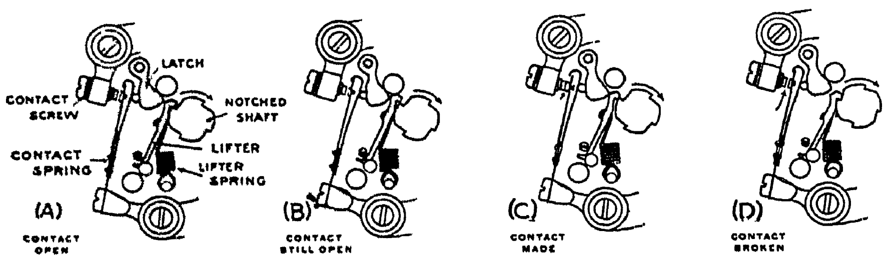


FIG 132. Operation of Atwater-Kent contact mechanism

Principle of Operation.—The action of the contact mechanism is shown in Fig. 132. The four views show the movement described in producing one spark. The principal moving parts are: the hardened steel rotating shaft in the center with as many notches as there are cylinders, the lifter, the latch, and the contact spring. The contact points are normally open. The contact is made and broken by the action of the lifter spring in drawing the lifter back, or after the lifter has become unhooked from the notched shaft. When the lifter is pulled forward by the notched shaft, it does not touch the latch. It is pulled forward until it reaches a point where it unhooks from the notched shaft and is then snapped back by the lifter spring, striking the latch as it returns. The latch, being struck by the lifter, presses against the contact spring and closes the points for a brief instant. The points open immediately after the lifter passes. With the latch and the lifter returned to their original positions, the mechanism is again ready to repeat the operation for producing the next spark. The spring action makes the speed of the break independent of the speed of the engine. It also makes the time of contact uniform and, since the period of contact is so brief, the system draws the least possible current from the batteries. This makes it particularly adapted for use with dry cells.

A complete wiring diagram of the type K-2 system using a switch of the polarity-changing type is shown in Fig. 133. The switch has two positions, "Off" and "On." When it is turned "On," if terminal *B* is connected to *S*, and *B'* to *S,'* the current will flow as indicated by the arrows. The next time the ignition is turned on, by turning the switch another quarter turn in the same direction, the connections in the switch are reversed, connecting *B* to *S,'* and *B'* to *S*. This reverses the direction of the primary current through the unisparker. The purpose of this

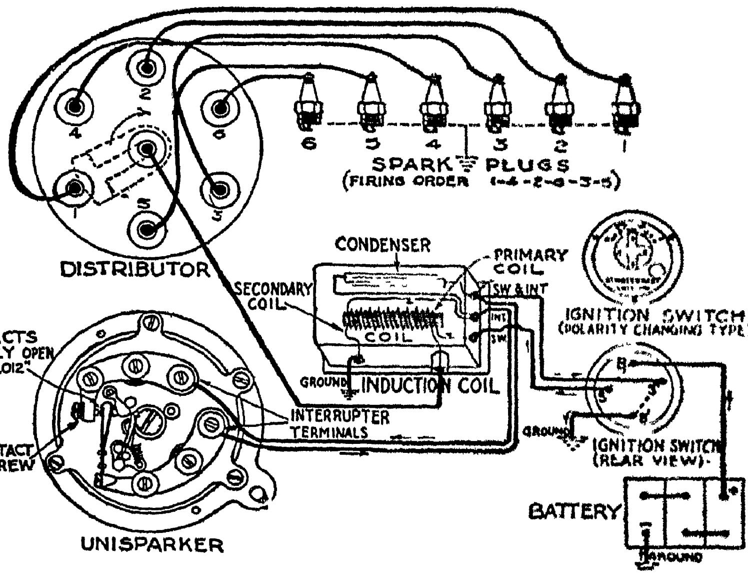


FIG. 133.—Circuit diagram of Atwater-Kent ignition system, type K 2.

is to equalize the transfer of metal by the action of the spark at the point of contact, thereby decreasing the wear and prolonging the life of the points.

The current flows through the primary winding of the ignition coil, while the contacts are making momentary contact. When the points separate, the coil demagnetizes and a high-voltage current is induced in the secondary winding. The secondary current is led to the center terminal of the distributor, from which point it is directed to the various spark plugs in their proper order of firing by the revolving distributor block.

Owing to the short period in which the contacts are together and the consequent short duration of the current flow, the coil used with such an interrupter must be designed to magnetize or *build up* rapidly, because it requires an appreciable amount of time for the primary current to rise to its full value, the time depending upon the quality and the shape of the core and the number of turns and size of wire in the primary coil winding. Thus, a slow-type coil designed to operate with a closed-circuit type breaker will not operate satisfactorily with one of the open-circuit type, since the points will generally open before the core becomes fully magnetized. On the other hand, a coil intended for the open-circuit type interrupter will be of too low resistance to give satisfactory service with a closed-circuit type of breaker, because the current flow will be abnormally high, usually causing rapid burning of the contact points and possible injury to the condenser.

Contact-point Adjustment.—The normal gap between the contact points is from 0.010 to 0.012 in.—never closer. When the gap becomes too wide, due to wear, the engine will be hard to start and will fire irregularly. The head of the contact screw, Fig. 133, is set up against several thin washers. A sufficient number of these washers should be removed to give the correct gap when the screw is set up tight.

The contact points are made of pure tungsten, a material which is many times harder than platinum. When the contact points are working properly, small particles of tungsten are carried from one point to the other, sometimes forming a rough surface characterized by a dark-gray color. This roughness does not affect the proper working of the points, because the rough surfaces fit into each other perfectly. When, however, it becomes necessary to take up the distance between these points, due to natural wear, it is advisable to remove both the contact screw and the spring contact arm and dress down the high spots with an oil stone or a new fine file. This will make it possible to obtain a more accurate adjustment and eliminate the danger of any high points on the contacts touching each other when the parts are at rest.

Automatic Spark-advance Mechanism.—The mechanism for automatically advancing and retarding the spark, as shown in Fig. 131, is located in the housing immediately below the interrupter. It consists of a system of weights and springs, arranged so as to advance the spark automatically as the engine speed increases. The timer shaft is divided, the upper portion being notched for operating the contact mechanism. As the speed increases, the weights fly outward because of the centrifugal force and the upper part of the shaft is shifted more and more ahead of the lower or driving shaft, thus causing contact to occur earlier and thereby advancing the spark. As the speed of the engine is reduced, the pull of the springs causes the weights to move inward, turning the upper or notched end of the shaft backward, or reverse to the direction of rotation of the driving shaft, thereby retarding the spark. The total amount of automatic spark advance at high speed is from 30 to 40 deg.

Timing the Spark.—Since the type K-2 breaker is not generally used with a spark-control lever, it should be installed so as to allow a small amount of

angular movement for the initial timing adjustment. In other words, the socket into which the unisparker fits should be provided with a clamp which will permit the unisparker to be turned and locked rigidly in any given position.

In timing, the piston in No. 1 cylinder should be raised to upper dead center between compression and power strokes. The clamp which holds the unisparker should then be loosened and the unisparker (the entire ignition unit) slowly and carefully turned backwards or counter-clockwise (opposite in direction to the rotation of the timer shaft) until a click is heard This click occurs at the exact time of the spark. At this point, the unisparker should be clamped, care being taken not to change its position. The distributor cap, which fits only in one position, should then be removed and the position of the distributor block on the end of the shaft noted. The terminal to which it points must be connected to No. 1 spark plug and the remaining plugs wired in turn to the other terminals in their proper order of firing, the direction of rotation of the timer shaft being kept in mind

When timed in this manner, the spark will occur in each cylinder exactly on *dead center* if the engine is turned over slowly. At cranking speeds and for safe starting, the spark is retarded automatically by the governor. As the speed increases, the spark is advanced automatically, thus requiring no attention on the part of the driver.

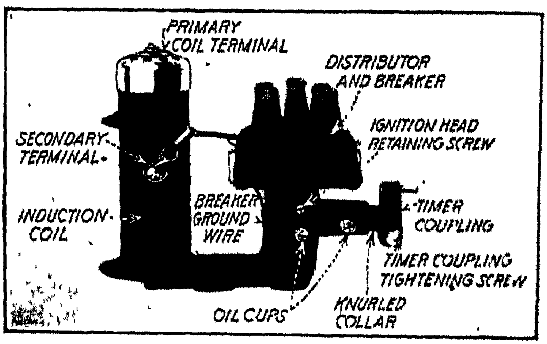


Fig. 134.—Atwater-Kent ignition unit, type CC.

112. The Atwater-Kent Ignition System—Closed-circuit Types.—The closed-circuit type Atwater-Kent ignition systems, as represented by the type CC unit, Figs. 134 and 135, and the type RA, Figs. 136 and 137, were developed for use on cars equipped with a starting and lighting system and are intended to operate on current from a storage battery.

The type CC unit, Fig. 134, is the earlier style of closed-circuit system and consists of a breaker and a distributor unit mounted with a non-vibrating coil on a base as shown. This unit has the same general dimensions as the standard high-tension magneto

and is driven in the same manner. For this reason it is termed a "magneto replacement unit." The circuit diagram of this system is shown in Fig. 138.

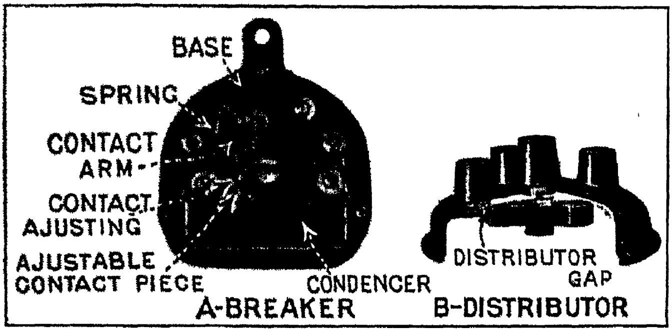


FIG. 135.—Breaker mechanism and distributor for Atwater-Kent unit, type CC

The principal feature of the Atwater-Kent closed-circuit system—either type—lies in the design of the breaker mechanism. These are shown in Figs. 135 and 137, which illustrate the type CC and type RA, respectively The contact mechanism consists of an exceedingly light steel contact arm mounted on a thin flat spring instead of swinging on a pivot as is the usual construction In the type CC breaker, Fig 135, the contact-arm fiber buffer, which rides on the cam, is located at the outer end of the arm, the contact points being between the buffer and the hinged end. In the type RA breaker, Fig. 137, the buffer is in the middle of the contact arm and the contacts are located at the outer end. The normal contact opening for the type CC breaker should be 0.006 to 0.008 in., preferably 0.006 in. This is slightly less than the thickness of two pages of this book. The type RA breaker should have a normal maximum opening of 0.015 in.

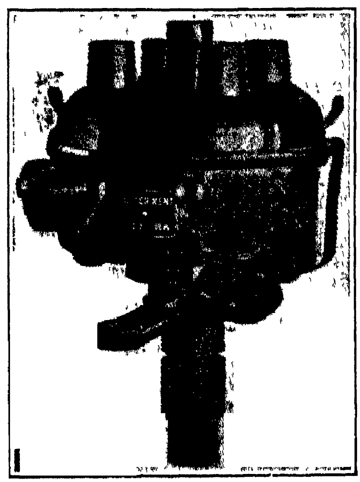


FIG. 136.—Atwater-Kent ignition breaker and distributor unit, type RA.

For use on four- or six-cylinder engines, the hardened-steel cam has four or six lobes, respectively, and rotates at one-half engine crankshaft speed. Each time the contact points are opened, the primary circuit of the ignition system is interrupted, thus producing a discharge of secondary high-tension current at one of the spark plugs. As shown in the circuit diagram for the type CC system, Fig. 138, a resistance unit is mounted in the top of the coil to provide protection to the coil and battery in case the switch is left on. It also assists in equalizing the secondary spark at high and low engine speeds, as previously explained.

The distributor head is of the gap type, the metal blade of the distributor arm just clearing the metal terminals in the cap without actually touching them. The high-tension current jumps this minute gap without appreciable loss when the contacts separate.

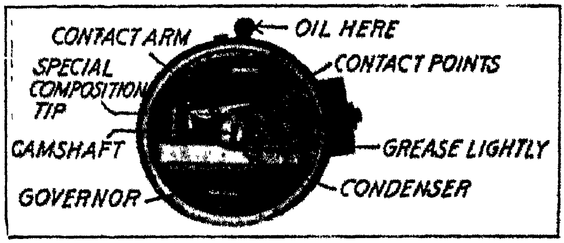


FIG. 137.—Atwater-Kent closed circuit breaker, type RA

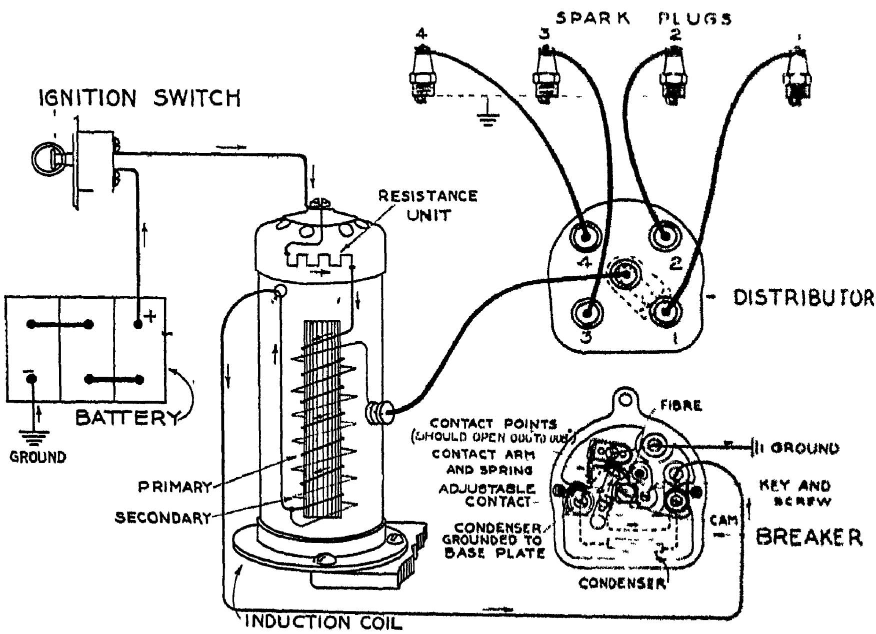


FIG. 138.—Circuit diagram of Atwater-Kent ignition system, type CC.

Another feature is the mounting of the condenser (in both types of breakers) beside the interrupter instead of in the coil housing. This makes it easy to reach in case of replacement or repairs, and, being connected directly across the contact points, permits the greatest condenser efficiency and con-

sequently results in long life for the points. The type RA breaker is equipped with an automatic spark-advance governor located in the breaker housing immediately below the cam.

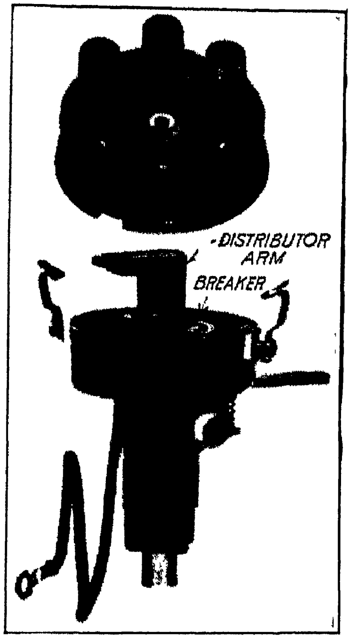
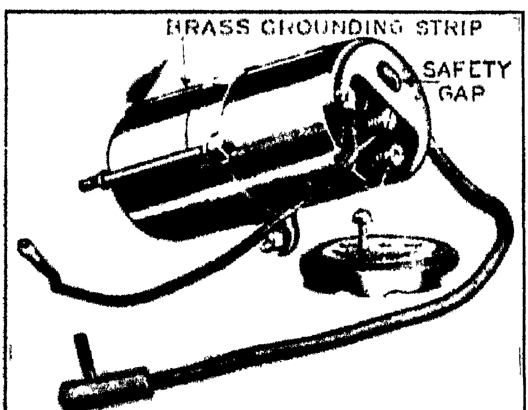


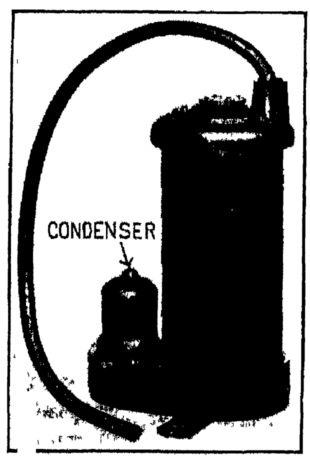
FIG 139.—Connecticut battery ignition breaker and distributor unit, model 18

113. The Connecticut Battery Ignition System. The principal parts of this system consist of a breaker and a distributor unit, a non-vibrating coil, and a switch. The breaker and distributor unit, known as the Model 18 igniter, is shown in Fig. 139 with the distributor cap removed. Figure 140 shows typical coil types and Fig. 141 the types of switches used. The 225-Y coil shown in Fig. 140*B* is the latest coil as introduced on many 1922 and 1923 cars. Its circuit diagram is as shown in Fig 142.

The breaker, Fig. 143, operates on the closed-circuit principle, the primary circuit being interrupted and the secondary spark produced when the lobes of the cam strike the roller of the contact arm. The cam has as many lobes as there are

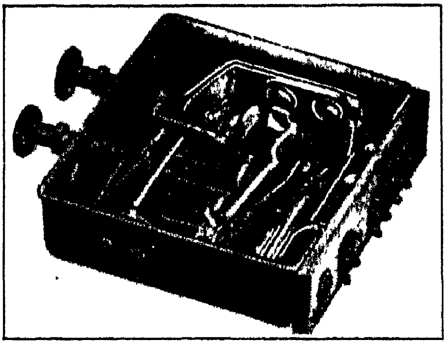


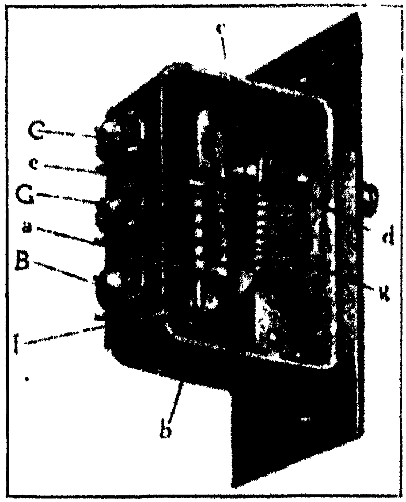
(*A*)



(*B*)

FIG. 140.—Types of Connecticut ignition coils.





(A) (B)

FIG. 141.—Types of Connecticut automatic kick out ignition switches. (A) Type H. (B) Type K.

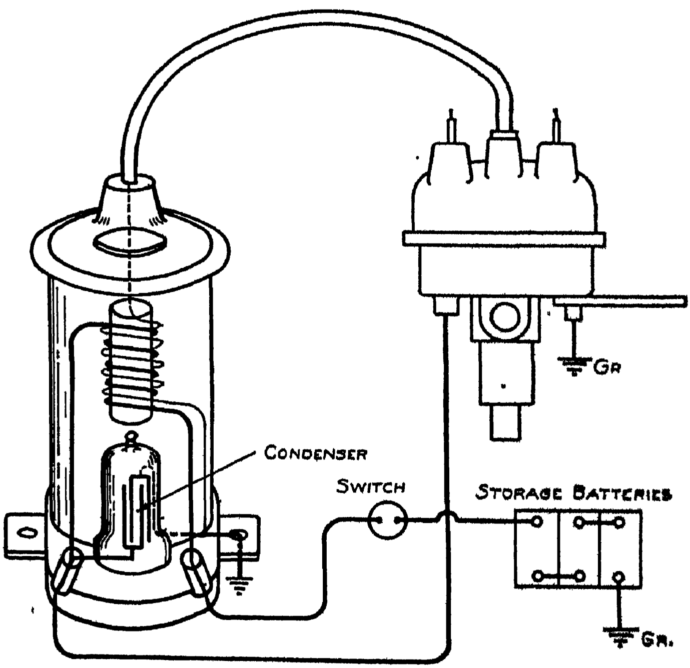


FIG. 142.—Circuit diagram of Connecticut ignition coil, type 225-Y.

cylinders and rotates at one-half crankshaft speed. It is not provided with an automatic spark advance.

The breaker mechanism is very simple, as Fig. 143 shows. It is mounted on a plate which rests in the casing and is held in

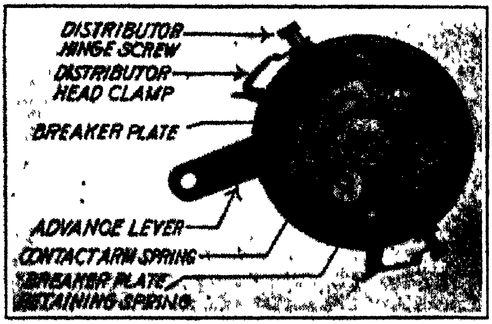


FIG. 143. Typical Connecticut ignition breaker.

place by a spring ring and also by a solid ring, the latter being held by two screws, as shown in Fig. 144. The advance lever engages a pin on the breaker plate, the whole plate being advanced

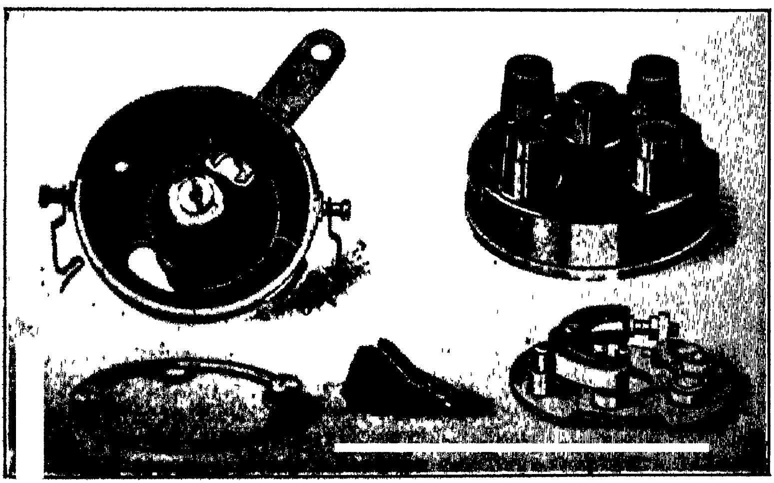


FIG. 144.—Disassembly view of Connecticut breaker.

around the shaft to advance the time of ignition. The contact points should be adjusted to open 0.015 to 0.020 in.

The distributor arm, which directs the secondary current to the various plugs in their proper order of firing, is carried above

the cam on the upper end of the same shaft. The distributor is of the gap type.

In many installations the igniter unit is mounted at the side of the engine and is driven through spiral gears from one end of the generator shaft. The coil, which also houses the condenser, is usually mounted close to the breaker either on the engine frame, or on top of the generator, and is connected to the breaker by short, flexible leads. A circuit diagram, typical for the older coil, is shown in Fig. 145. This also shows the circuits of the type H ignition switch. One side of the condenser, as well as one side of the primary and secondary winding, is grounded through the brass strip on the side of the coil to the coil base and engine frame. The condenser, although mounted in the coil, is connected across the interrupter points through the two short leads which connect the coil with the breaker terminals. Its purpose is to protect the points against pitting, as previously explained.

The Automatic Kick-out Switch.—One of the distinct features of the Connecticut ignition system is the switch which is provided with an automatic "kick-out" mechanism for releasing the switch and thus opening the primary battery ignition circuit in case the switch should be accidentally left "On" with the engine not running. The purpose of this is to safeguard against undue draining of the battery and to prevent over-heating of the ignition coil.

The switch is made in two principal models, known as type H, Fig. 141*A*, and type K, Fig. 141*B*, the latter being of the later design and introduced on many 1919 and 1920 cars. When the switch is mounted integral with the lighting switch, the complete switch unit or panel is known as types H-ND and KVD, respectively.

A complete circuit diagram of the Connecticut system using the type H-ND switch is shown in Fig. 145. When the ignition button (the left-hand button to the driver) is pushed in, the primary current from the battery completes its circuit as indicated. The current flows from the positive battery terminal to the switch terminal *B*, then through the switch contacts and resistance element to the switch terminal *C*, which is connected to the terminal *C* on the ignition coil. The current then flows through the primary winding of the coil to the stationary side of the igniter, across the breaker points to the grounded terminal of the coil, returning to the negative terminal of the battery through the ground. The current induced in the secondary winding of the coil, upon interruption of the primary, flows from the secondary winding to the center of the distributor, through the distributor arm to the spark plug, across the plug, and back to the grounded coil terminal. It will be seen that a safety gap is provided in the top end of the coil. It is inclosed in a mica tube inaccessible to vapor or fumes yet is

under a mica window, so that the spark may be readily observed in the case of a misfiring cylinder. The purpose of this gap, as previously explained, is to protect the secondary winding from the destructive action of the high voltage in case a plug terminal should become disconnected and the high-tension current thus prevented from taking its regular path. The ignition is turned off by simply pushing in on the "Off" button, which will release latch *G*, allowing the "On" button to fly out and the switch contacts to open.

Operation of Automatic Switch, Type H.—A study of Fig. 145 will also show the principle of the automatic switch mechanism. The thermostat is composed of two strips of dissimilar metals, nickel steel and spring brass, welded along their entire surface, fixed at one end, and wound with a heating element (insulated by mica) similar to that used for resistance units. Brass expands with an increase in temperature much more rapidly than nickel

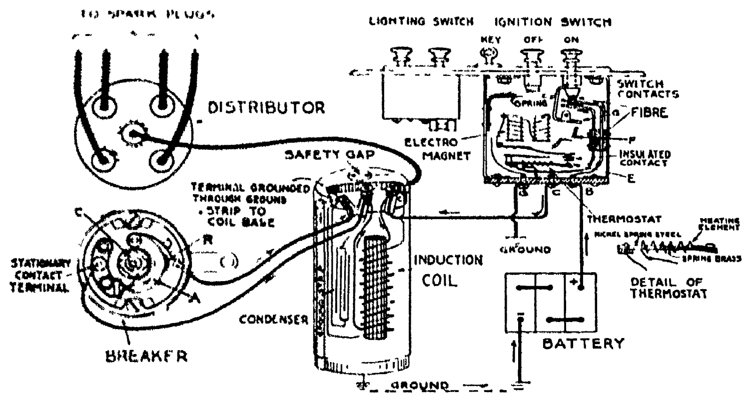


FIG. 145.—Circuit diagram of Connecticut ignition system using type H switch.

steel; consequently, the thermostat blade, being fixed at one end, will bend as it is heated in proportion to the increase in temperature. (It should be noted that the resistance unit is regularly in the primary ignition circuit.)

In case the switch is left "On" with the engine not running and the breaker points, closed the continuous flow of current through the resistance unit will cause the thermostat blade to heat and bend sufficiently to close the contacts *E*. This will complete a circuit from the battery through the winding of the electromagnet, causing the arm *F* to vibrate rapidly. The end of arm *F*, upon striking the lever *G*, automatically releases the switch button. The thermostat can be adjusted to operate at any time after the engine is stopped from 30 sec. to 4 min. This adjustment is made after the engine stops by varying the gap of the thermostat contacts. The normal setting should be such as to release the switch in about three-quarters of a minute.

Operation of Automatic Switch, Type K.—The automatic switch type K differs from type H principally in the arrangement of the thermostats, two

being employed instead of one, and in the method of releasing the switch button, as may be seen by comparing Figs. 141*A* and *B*. A circuit diagram of a typical ignition system using the type K switch is shown in Fig. 146. The operation of this switch is as follows: With the switch button plunger *c*, Fig. 146, pushed in, the contacts *h* are closed and the primary circuit is completed through the thermostatic bar *b* and heater tape *e*, the current entering the switch at terminal *B* and leaving at terminal *C*. The switch button is held in by a fiber wedge-shaped block mounted on the free end of a second thermostatic bar *d*, the fixed end of which is grounded to the switch case and electrically connected to terminal *G*, which is also grounded. If the switch is left "On" and an uninterrupted flow of current is allowed to pass through the heater tape *e*, the thermostatic bar *b* will bend down until it makes contact with the adjustment screw *f*. This will allow current to

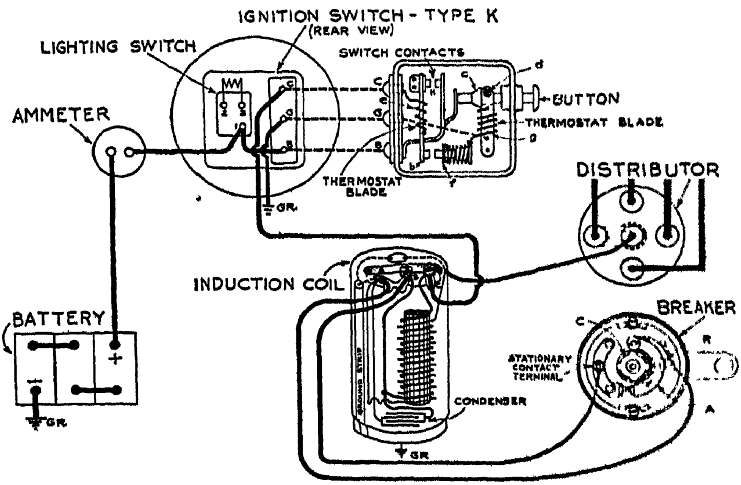


FIG. 146.—Circuit diagram of Connecticut ignition system using type K switch.

flow from the battery through the heater tape *g* to the ground post *G*, causing the thermostatic blade *d* to bend up sufficiently to release the switch button plunger *c*, thus opening the switch contact *h*. The switch can also be turned off by pulling plunger *c*, which will release the latch and accomplish the same result.

The time in which the switch will release itself after the engine has stopped may be regulated by turning the adjustment screw *f*. The time for release may be increased by increasing the gap between the contacts slightly, and decreased by decreasing the gap. The normal adjustment should be such that the release of the switch will occur in about three-fourths of a minute after the engine stops, the same as for the type H switch.

Inasmuch as the system operates on the closed-circuit principle, the maximum time is allowed for the complete magnetization of the induction coil. The intensity of the sparks produced at the plugs depends upon this

magnetization. It follows that the slower the speed of the engine the greater the magnetization of the core and the greater the spark intensity. However, this is partly counteracted by the action of the resistance unit surrounding the thermostat. This resistance unit tends to equalize the intensity of the secondary spark at high and low engine speeds in exactly the same way as the resistance units in other systems.

114. The Remy Battery Ignition System.—The Remy battery ignition system, which is of the high-tension distributor type, consists principally of a vertical breaker unit, Fig. 147, a non-vibrating coil, such as that shown in Fig. 148, and a switch, which may be of either the plain or the polarity-changing type. The ignition switch is usually combined with the lighting switch.

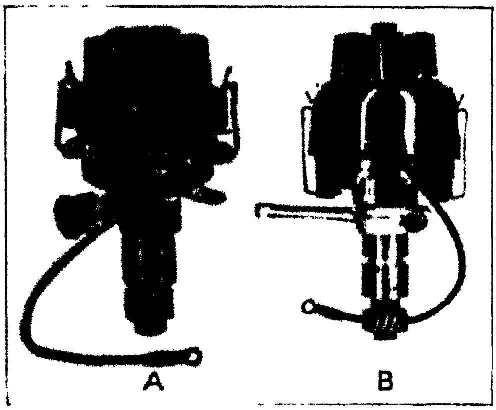


FIG. 147.—Types of Remy battery ignition breaker and distributor units. (A) Older type. (B) Newer type.

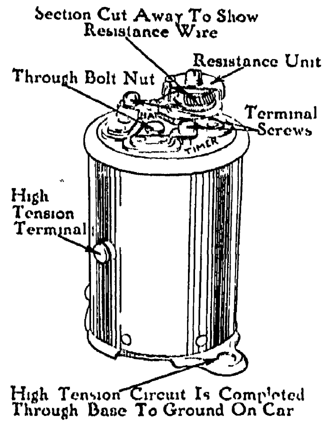


FIG. 148.—Remy ignition coil two primary terminal type

The two distributor units shown in Fig. 147 are typical of those furnished on a great many cars, *A* being the older type while *B* is the later model. Details of the older type breaker were shown in Fig. 125. Circuit diagrams showing the two types of breakers and the coils used are shown in Figs. 149 and 150, respectively. As will be noted, the two breaker designs are very similar, both being of the closed-circuit type. The principal difference is that in Fig. 150 the condenser is mounted on the breaker plate where it is very accessible, while in the older system it is located in the coil. There is also a slight difference in the contact-arm design and in the method of mounting the buffer.

The two types were also shown in Fig. 126, in which A and B represent the old and new types respectively.

In both types of breakers the cam is made adjustable for timing purposes. It makes a taper fit on the upper end of the timer

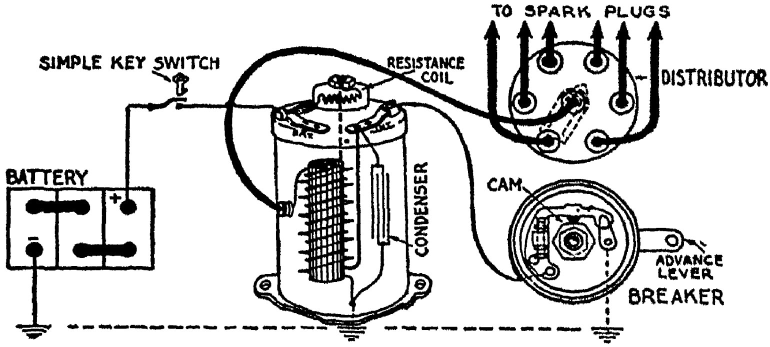


FIG. 149—Wiring diagram for Remy battery ignition system using two-primary-terminal coil containing condenser.

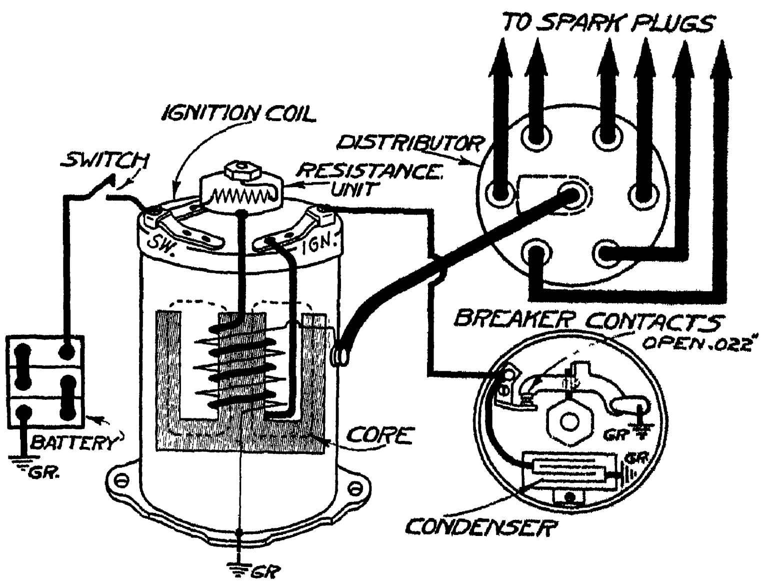


FIG. 150.—Circuit diagram of Remy battery ignition system using two-primary-terminal type coil with condenser in breaker assembly.

shaft and is held in place by a lock unit on the upper end of the shaft. On the upper side of the cam, a short pin projects. The distributor arm must fit over the pin when the arm is properly

located in position. The breaker contacts are of tungsten and should be adjusted to have a maximum opening of 0.020 to 0.025 in. The distributor is of the gap type, the gap being approximately $\frac{1}{64}$ in.

The Ignition Coil. A special feature of the coil is the use of a three-legged or W-shaped core, as shown in Fig. 89. As Figs. 89 and 150 show, the primary and secondary windings are wound over the middle leg of the core. The other two legs act as external cores there being a comparatively short air gap between their ends and the top of the middle leg for the magnetic flux to span. The result is an efficient type of coil. Due to the use of the external core, however, the coil is not an exceptionally fast one, being designed especially for use with closed-circuit-type breakers.

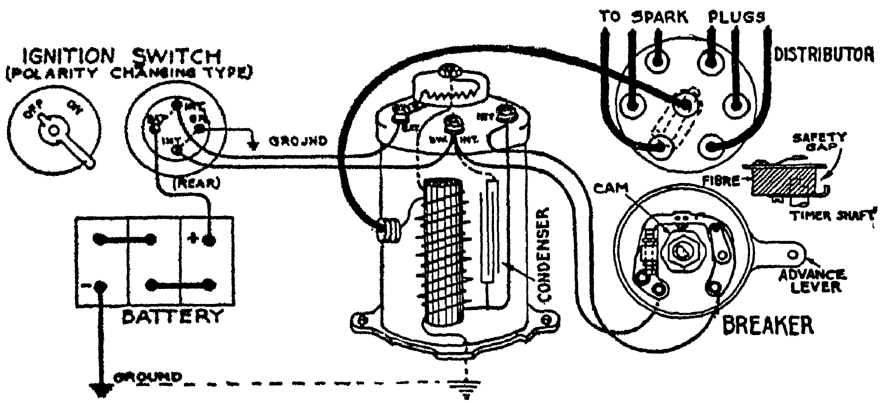


FIG. 151.—Wiring diagrams of Remy ignition system using three-primary-terminal type coil and polarity changing type switch

Therefore, no attempt should be made to use this coil with the open-circuit-type breaker, for example, the Atwater-Kent type K-2.

When used with Remy breakers of the older type, the coil assembly includes also the condenser (which lies beside the coil), one side being connected to the primary terminal which connects to the breaker, while the other is grounded to the metal base—as is also one end of the secondary winding. For use with the later type of breaker, the coil assembly does not contain a condenser, since this is mounted on the breaker plate where it is a self-contained unit easily removed or replaced.

The Three-primary-terminal-type Coil. In some of the earlier installations it was desired to change the polarity of the breaker contacts each time the switch was turned on. Thus a coil was used having three primary terminals on top, one being used simply as a condenser connection, as shown in Fig. 151. In this system both sides of the breaker are insulated, the ground connection for the primary circuit being made through the polarity-changing-type switch.

A safety gap located in the distributor is also provided in this system. This safety gap consists of a ⅜-in. gap located between one end of the distributor-arm segment and the upturned end of a brass plate attached to the lower side of the arm, being connected to the ground through the timer shaft as shown in Fig. 151. In the later models no safety gap is provided.

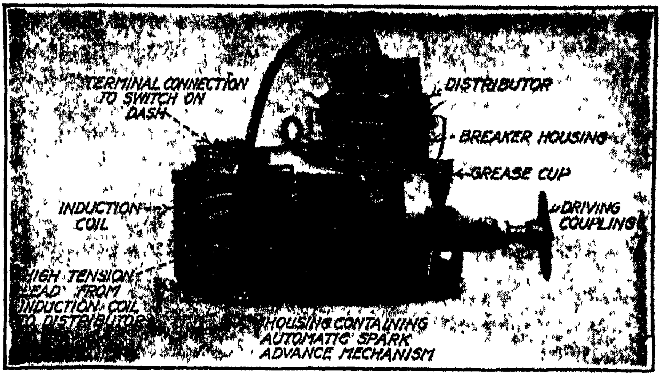


FIG. 152.—North East ignition unit, model O, used on Dodge car.

115. The North East Ignition System.—A representative type of the North East ignition system is shown in Fig. 152, which shows the type 10004, Model O, ignition unit as used on the Dodge car.

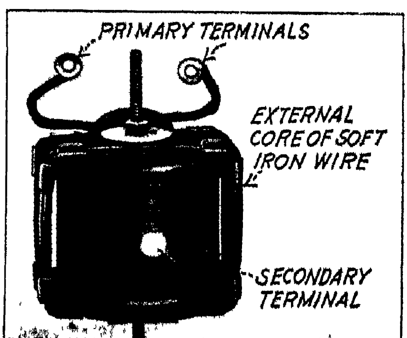


FIG. 153.—North East ignition coil removed from housing.

The installation of the system on the Dodge car is shown in Fig. 122. The ignition unit, Fig. 152, is virtually a magneto replacement outfit, being driven the same as a magneto. This unit comprises an induction coil, Fig. 153; a breaker of the closed-

circuit type, Fig. 154; a condenser mounted in the breaker housing as shown; an automatic spark-advance mechanism, Fig. 155; and a distributor of the wipe-contact type, as shown in Fig. 154.

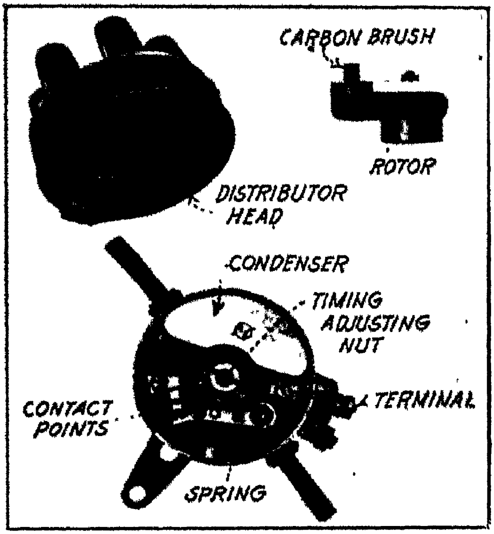


FIG. 154 North East breaker-distributor showing distributor head and rotor removed

Two types of breakers are in use. In one type the terminals of the breaker are both insulated and the system operates with a polarity-changing-type switch. In the other type, Fig. 154

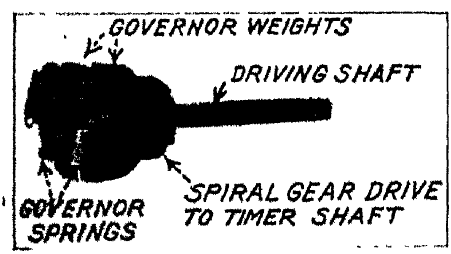


FIG. 155. Automatic spark advance mechanism used in North East model O ignition unit.

(the latest design), one breaker terminal is grounded and the system operates with a simple key switch. A circuit diagram of the Model O system on the Dodge car is shown in Fig. 156.

The Coil.—One of the features of the system is the coil, Fig. 158, which is of the closed-core type and housed in a cast-iron casting at one end of the

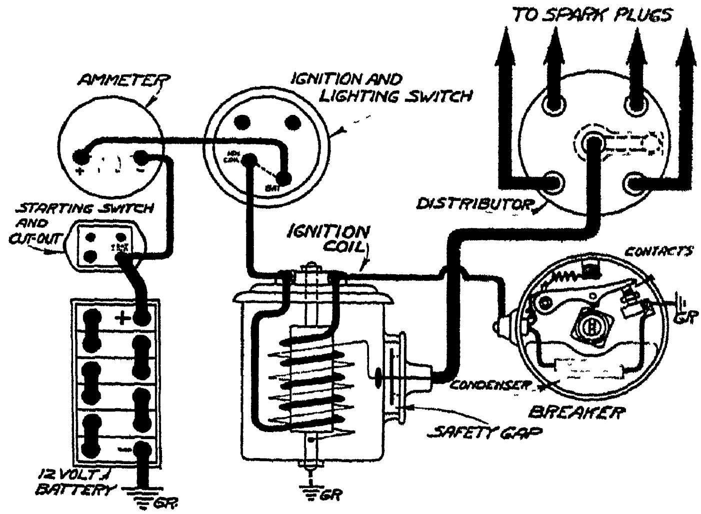


FIG. 156.—Circuit diagram of North East, model O, ignition system as used on Dodge car.

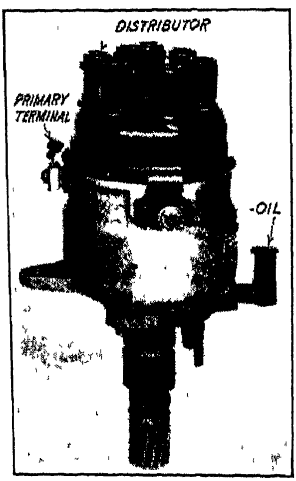


FIG. 157.—Typical Delco ignition breaker and distributor unit.

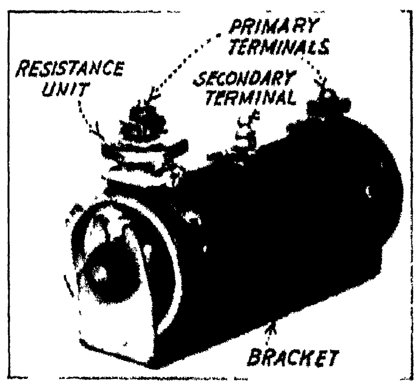


FIG. 158.—Typical Delco ignition coil.

unit. After the coil is constructed on its core, a wrapping of soft-iron wire, which connects the two pole ends as shown, is put on. This provides two soft-iron external paths through which the coil magnetism can

flow so that comparatively little magnetism will pass through the cast-iron housing. The characteristics of the coil are such that no resistance unit is needed. As a protection to the coil insulation, a safety gap is pro-

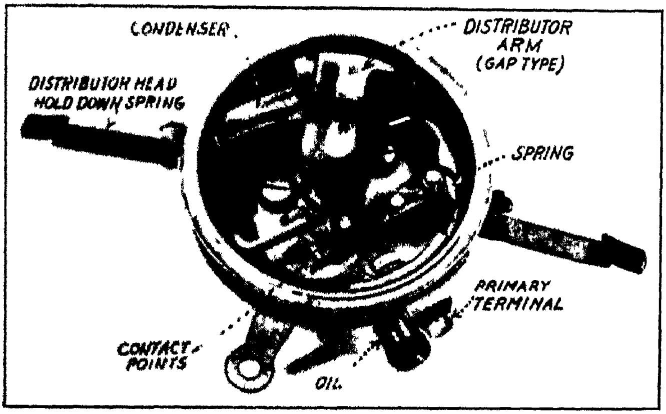


FIG. 159.—Typical Delco breaker, showing model used on U S Liberty military truck.

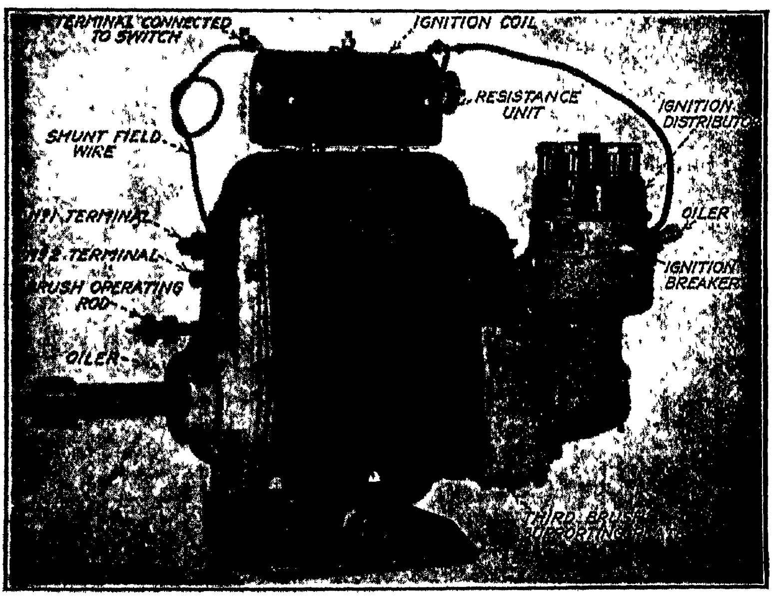


FIG. 160.—Delco ignition equipment mounted on motor-generator for Buick Six.

vided, located between the washer on the inside of the high-tension coil terminal and the screw thread of the coil housing, as shown in Fig. 156.

The principles of operation of the system are very similar to those of the other systems of the closed-circuit type equipped with automatic

spark advance. To assist in timing the ignition, the cam is made adjustable and can be loosened by the nut which tightens it to the timer shaft. The contacts are of tungsten and should be adjusted to open 0.020 in.

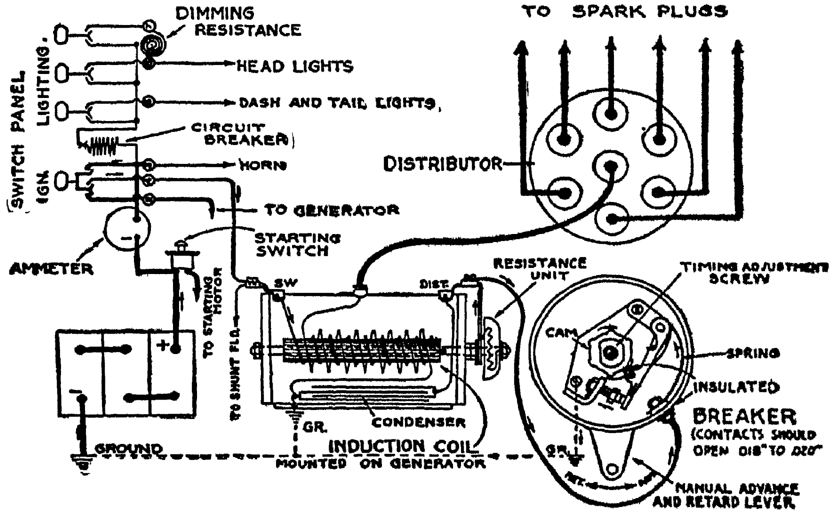


FIG. 161.—Circuit diagram of Delco ignition system typical for 1917 and 1918 cars.

116. The Delco Ignition System.—Many types of Delco ignition equipment have been used to satisfy the ignition require-

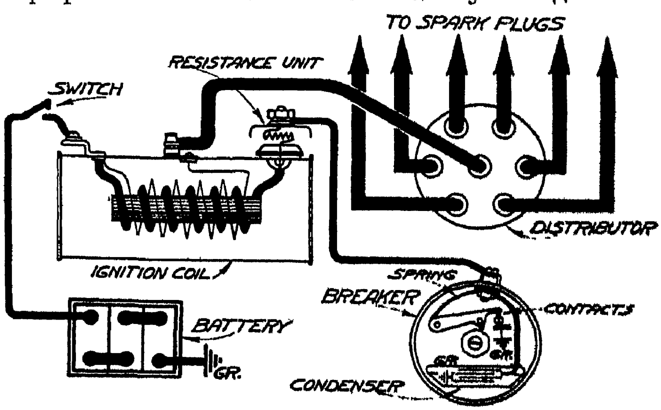


FIG. 162.—Circuit diagram of typical Delco ignition system with condenser mounted on breaker plate.

ments of the large number of cars using this make of system. Figure 157 shows a typical breaker-distributor unit, while Fig. 158 shows one type of coil which has been widely used. The dis-

tributor unit shown in Fig. 157 is the type commonly used when driven either from the engine or from the generator shaft through spiral gearing.

Typical Delco breaker construction is shown in Fig. 159. It is of the closed-circuit type, the condenser being mounted either on the breaker plate, as shown, or in the bottom of the coil, which is usually mounted close by on the generator, such as in

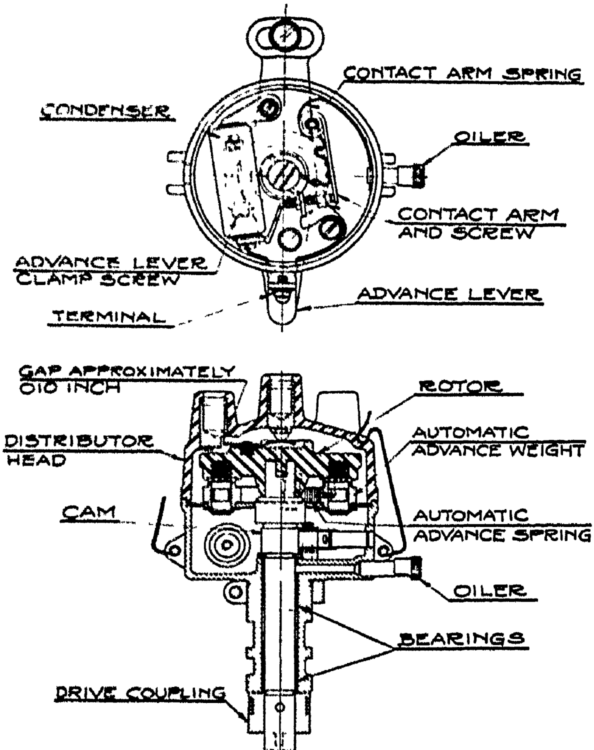


FIG. 163.—Late Delco ignition unit using gap type distributor.

Fig. 160. A circuit diagram typical of the systems used prior to 1919 is shown in Fig. 161, while Fig. 162 shows the wiring of the equipment as used very widely on four- and six-cylinder cars since 1918. In the systems shown, the resistance unit is mounted on the coil, but this may be found located on the side of the breaker housing in many installations. The style of coil used may also vary considerably, depending upon the type of breaker employed.

In both styles of ignition breakers shown, automatic spark advance is provided through a revolving-weight-type governor located immediately below the breaker. The distributor may be of either the wipe-contact or the gap type, the contact type being used almost exclusively prior to 1923, while the gap type is the latest development, having been introduced on many 1923 and 1924 cars, particularly those using the Continental engine. The usual breaker contact opening is 0.018 to 0.020 in.

The Delco Gap-type Distributor Unit.—A cross-sectional view of the Delco gap-type distributor unit, such as introduced on several 1923 and 1924 cars, is shown in Fig. 163. As will be noted in the view of the breaker, the contact arm has been made much lighter and the buffer placed closer to the contact points. Another important change is the location of the automatic spark-advance mechanism, which is mounted on the under side of the distributor rotor and above the breaker, instead of below it, as is the usual practice. Circuits of the system are similar to those of previous Delco models. The contacts should be adjusted to open 0.020 in., as in previous models.

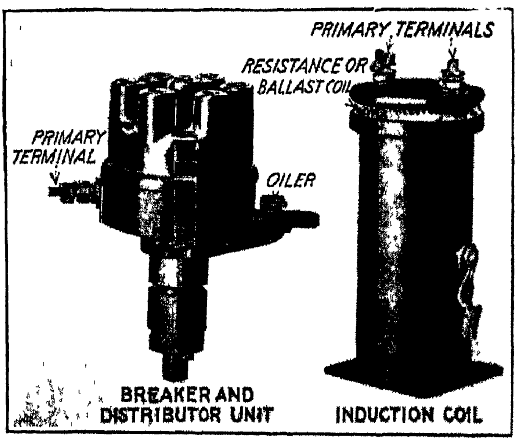


FIG. 164.—Westinghouse distributor unit and induction coil for type SC ignition system.

117. Westinghouse Battery Ignition System - Type SC. The Westinghouse type SC battery ignition system is a closed-circuit-type system, the principal parts of which are a distributor unit and a tubular-type coil, shown in Fig. 164. As will be noted in Fig. 165, which shows the interior view of the breaker, the condenser is incorporated with the breaker assembly, one side being connected to the insulated breaker terminal and the

other being grounded. It will also be seen that the movable contact point is mounted upon a steel spring, which flexes under the action of the interrupter cam, giving the contact

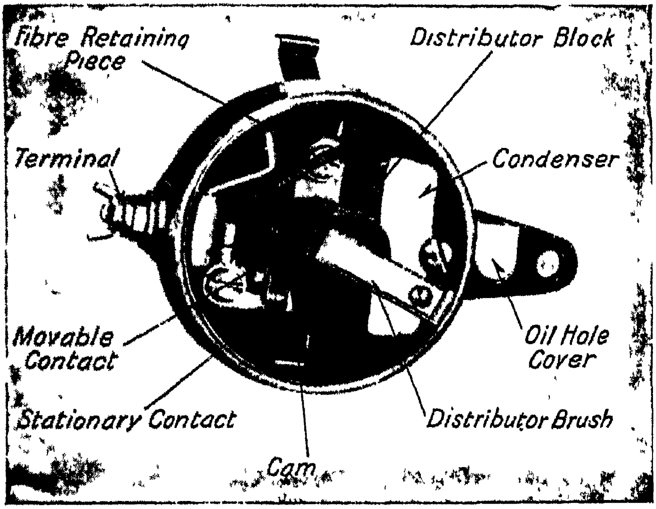


FIG. 165.—Interior of Westinghouse type SC breaker.

points a wiping contact as they open and close, thus reducing pitting. The contacts are of tungsten and should open 0.010 in. Another special feature is that the cam is molded of synthetic

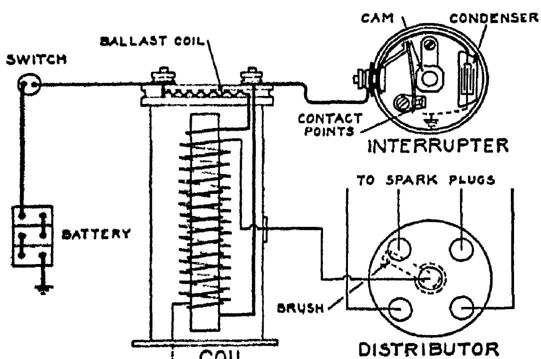


FIG. 166.—Circuit diagram of Westinghouse, type SC, battery ignition system.

Bakelite and graphite, instead of steel. This construction makes it self-lubricating and very durable. A circuit diagram of the system is shown in Fig. 166.

118. The Wagner Ignition System.—The principal parts of the Wagner ignition system consist of the distributor unit,

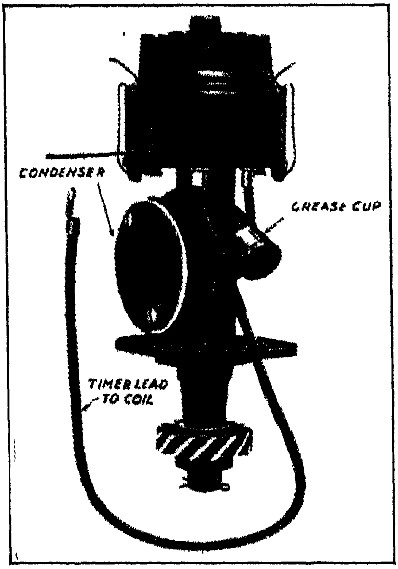


Fig. 167.—Wagner ignition distributor unit.

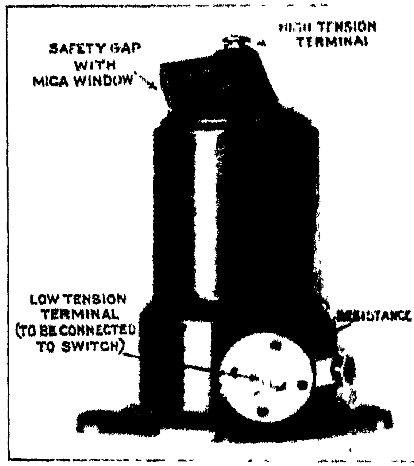


Fig. 168.—Wagner ignition coil.

Fig. 167, and the ignition coil, a typical example of which is shown in Fig. 168. The breaker is shown in detail in Fig. 169,

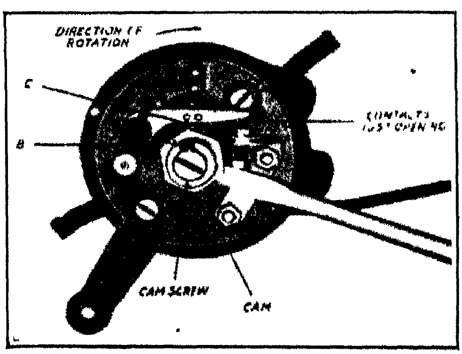


Fig. 169.—Wagner breaker showing method of removing cam for timing.

while a complete circuit diagram is given in Fig. 170. As may be seen from Figs. 169 and 170, the breaker is of the closed-circuit type, the condenser being located on the side of the breaker

unit. The cam is tightened in place by an adjusting screw, which should be loosened for adjusting the cam position when timing is necessary. The contacts are of tungsten and should be

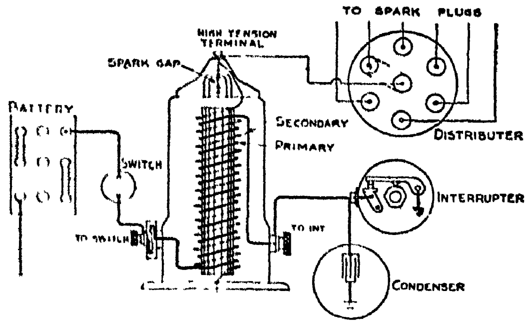


FIG. 170. Circuit diagram of Wagner ignition system.

adjusted to open a maximum of 0.020 in. The operation of the system is similar to that of other closed-circuit types previously described. The distributor is of the gap type.

119. The Bosch Battery Ignition System—Type T.—The Bosch battery ignition system comprises chiefly a vertical ignition unit which operates

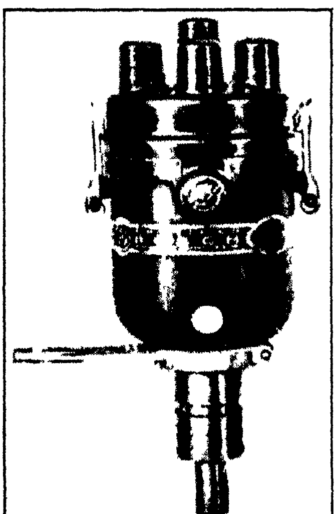


FIG. 171.—Bosch battery ignition distributor unit, type T.

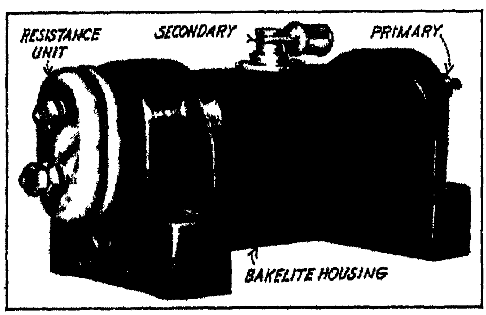


FIG. 172.—Bosch ignition coil, type TC.

in conjunction with a non-vibrating-type coil. Typical distributor and coil units as furnished on several prominent cars are shown in Figs. 171 and 172 respectively. The distributor unit

is furnished in two types, the type T, as shown in Fig. 171, being provided with an automatic spark-advance governor and type TM, equipped with manual advance only.

As may be seen from Fig. 173, the breaker is of simple design, being of the closed-circuit type with the condenser mounted on the breaker plate. The contacts are of tungsten and should be adjusted normally to open 0.015 to 0.020 in.

The Automatic Spark-advance Governor.—The automatic spark-advance governor, Fig. 174, which is located immediately below the breaker, is of the "tilting-ring" type and, together with the breaker cam and rotor, is

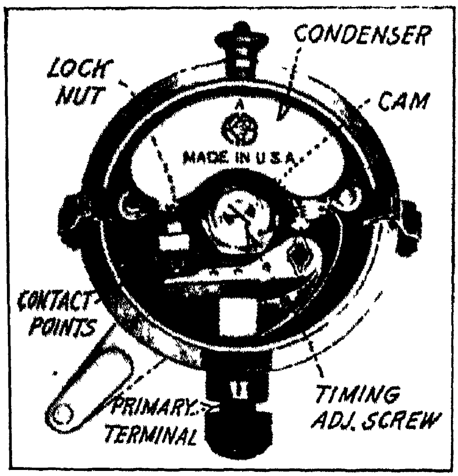


FIG. 173.—Bosch battery ignition breaker.

carried on the timer shaft. The range of ignition advance is determined by an advance control stud integral with the governor mechanism.

As the timer shaft rotates, the resultant tilting movement of the governor ring, due to centrifugal force, advances the interrupter cam (which is assembled to the timer shaft in the form of a sleeve) by direct engagement of a stud projecting into a slot provided in this sleeve. The total throw of the governor ring is adjustable by means of stop pins.

In order to provide the proper movement of the cam at different engine speeds, the tilting of the ring is opposed by an adjustable spirally wound spring, Fig. 174*B*, located in a recess in the bearing hub of the ring. This spring has not only been made adjustable with relation to the ring for varying the initial tension of the spring, and thereby controlling the speed at which the advance mechanism becomes operative, but various springs of different tension may be provided so that the required advance may be selected and assembled in the unit according to the engine requirements.

The governor construction is such that, without necessarily changing the angle through which the governor ring tilts, the total advance of the breaker cam may be set for any degree of advance from 0 to 60 deg., or even more, as measured on the engine flywheel.

The Bosch Type TC Coil.—The outstanding feature of the type TC coil, Fig. 172, is the core, which is made up of a large number of small soft-iron wires of exceptionally high permeability. In the center of the core is a metal tube through which passes the securing bolt for holding together the different components of the core and the casing. The ends of the core wires project beyond the wound core and are bent over in "umbrella fashion," being covered with a soft-iron band. This has the effect of an

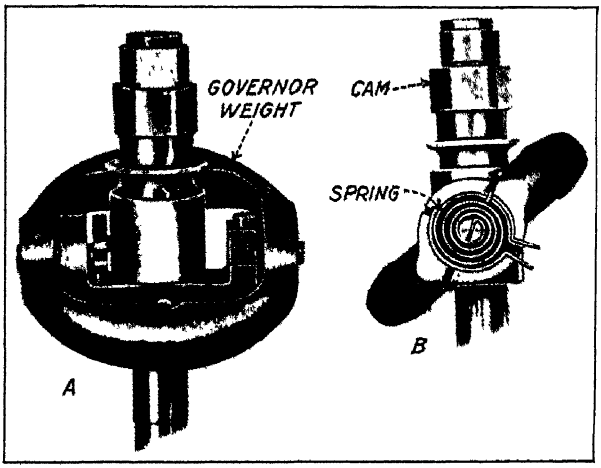


FIG 171 Bosch automatic spark advance governor, type T. (*A*) Top view. (*B*) Side view.

external core and adds materially to the efficiency of the coil. The resistance unit is carried on one end of the coil, as shown in Fig 172.

120. The Bosch Type 600 Ignition Unit with Type TC-30 Coil. The Bosch distributor unit, type 600, Fig. 175, and ignition coil, type TC-30, Fig. 176, were developed primarily for Ford cars equipped with a starting and lighting system using a storage battery.

The breaker unit, taking the place of the usual Ford timer, is designed to operate through spiral gears from the front end of the camshaft. The breaker is practically the same as that used in the type T distributor unit, Fig. 173, except that the automatic spark-advance governor, which is incorporated below the

breaker, is of the "spreading-weight" type instead of the tilting-ring construction.

The special feature of this system is the coil, a cross-sectional view of which is shown in Fig. 176*B*. The windings are arranged in rather an unusual manner, in that the primary winding which carries the low-tension current is wound around the outside of the high-tension secondary winding. Furthermore, as may be seen from the illustration, the housing of the coil is a steel casing with a double row of soft-iron wires arranged vertically between it and the primary winding. This construction allows any heat that may be generated in the primary winding to be readily dissipated

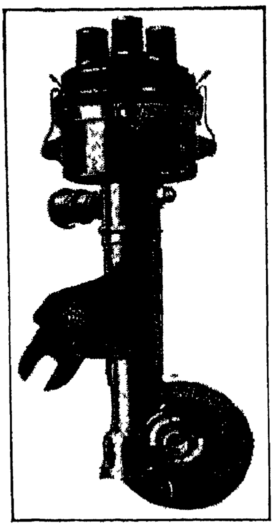


Fig. 175.—Bosch battery ignition unit, type 600, for Ford cars.

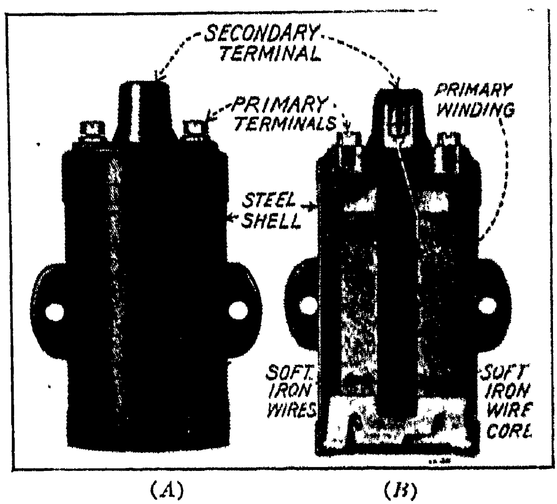


Fig. 176.—Bosch, type TC-30 ignition coil. (*A*) External view. (*B*) Sectional view.

through the steel casing, and also provides an external core for the coil, which, in combination with the main middle core, greatly increases the efficiency of the magnetic circuit. The result is an unusually high coil efficiency; in fact, the cooling feature, together with the electrical and magnetic characteristics included in the coil eliminates the necessity of a resistance unit, which is required with most coils.

121. General Procedure in Timing Battery Ignition with the Engine.—The details connected with ignition timing depend somewhat on the make and type of ignition system and also on the type of engine. The general principles, however, are the same. The following rules for timing a four-cylinder engine,

with minor modifications to suit certain individual conditions, will apply generally to all systems of the closed-circuit type having an adjustable interrupter cam.

Place the spark lever on the steering wheel in the fully retarded position, making sure that the interrupter timer lever is fully retarded and that all play in the connecting mechanism from the spark lever to the timer has been taken up.

With the petcocks open or the spark plugs removed, turn the engine over slowly by hand. After noting the firing order, either by testing the order of compression or by watching the operation of the valves, turn the engine until the dead-center mark on the flywheel for Nos. 1 and 4 cylinders (*D.C.* 1-4) is about 1 in. past the dead-center position for No. 1 cylinder. (One inch measured on the rim of a 16½-in. flywheel measures off about 7 deg. of the crank angle.) In a four-cylinder engine, the exhaust valve in No. 4 cylinder should just be closed with this setting.

Remove the distributor head and loosen the timing adjusting screw or nut in the center of the timer shaft. Turn the breaker cam so that the distributor brush or button will be in the position under No. 1 high-tension terminal when the distributor head is fastened in the proper position. In this position, adjust the breaker cam carefully, so that, when the distributor arm is rocked forward, taking up the slack in the gears, the contacts will be opened by the breaker cam, and, when the arm is rocked backward, the contacts will be closed.

Tighten the adjustment screw or nut securely and replace the distributor arm and head The head should be properly located by the locating tongue and the hold-down clips. The distributor should be wired to the plugs in the proper order of firing, beginning with No. 1 and proceeding around the distributor head in the direction of normal rotation.

SECTION VII

SPECIAL BATTERY IGNITION SYSTEMS, FOR SIX-, EIGHT-, AND TWELVE-CYLINDER ENGINES

122. Multiple Breakers.—As the number of cylinders on an engine increases, naturally the complication of the ignition system increases. In six-, eight-, and twelve-cylinder engines these systems become more or less special, in that they involve special design to meet the particular engine ignition requirements. It has been previously pointed out that in both the open- and closed-circuit ignition systems the maximum speeds at which they may be successfully operated are limited. The difficulties encountered at high speeds are of both an electrical and a mechanical nature. The coil must be fast enough for high-speed service, yet give proper ignition at low speed. At the same time, the breaker must be capable of doing its work accurately in order that the coil may function properly. To overcome these difficulties, multiple breakers are generally used, thus causing increased complication in ignition parts and wiring.

Types of Multiple Breakers.—Two principal schemes are used in the operation of multiple breakers: (1) one in which each breaker opens a separate circuit, and (2) one in which the two breakers operate in parallel with each other in the same circuit.

123. Delco Dual System for Pierce-Arrow and Stutz Engines The Pierce-Arrow engine used for passenger-car purposes is of the T-head-type construction, with two inlet and two exhaust valves for each cylinder. Because the combustion chamber is considerably spread out, two spark plugs are used in each cylinder head, one over the intake valve, the other over the exhaust valves, both being arranged to provide ignition sparks at the same instant. A similar arrangement is used on the Stutz engine. The purpose of this arrangement is to cut down the period of flame propagation, thereby reducing the angle of required spark advance and increasing the engine horsepower.

By igniting the gas at two points simultaneously it has been found that better combustion is obtained, as well as an increased horsepower and a

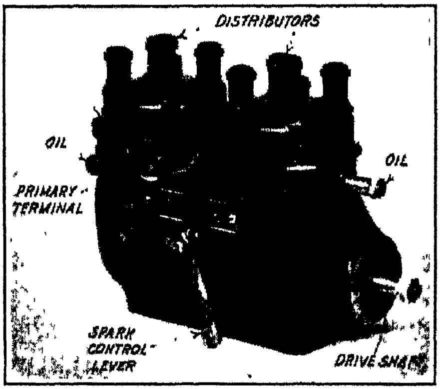


FIG 177.—Delco dual ignition unit as used on Stutz and Pierce-Arrow.

decreased fuel consumption. In the Pierce-Arrow engine (as well as the Stutz) the Delco dual system is used in order to provide two ignition sparks simultaneously in each cylinder. The breaker and distributor unit (Stutz

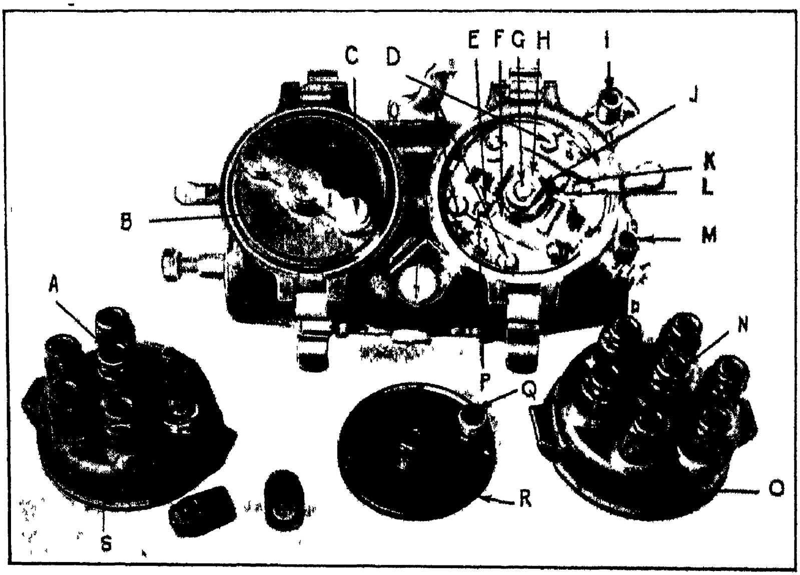


FIG. 178.—Pierce-Arrow ignition unit showing distributor and interrupter mechanism.

type) is shown in Fig. 177. A double-type breaker, as shown in Fig. 178, two condensers, and two distributors, as shown in Fig. 179, are contained in the

single unit. These operate in conjunction with two induction coils and two sets of spark plugs arranged as previously mentioned.

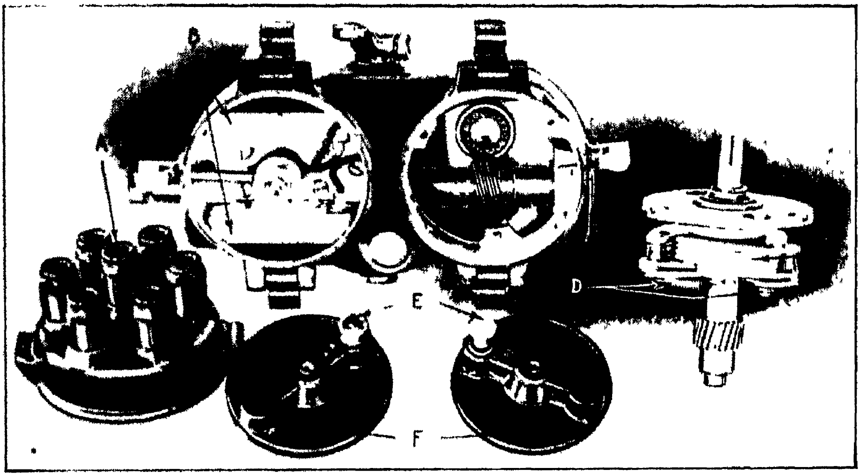


FIG. 179 Pierce-Arrow ignition unit showing condenser mounting and driving mechanism.

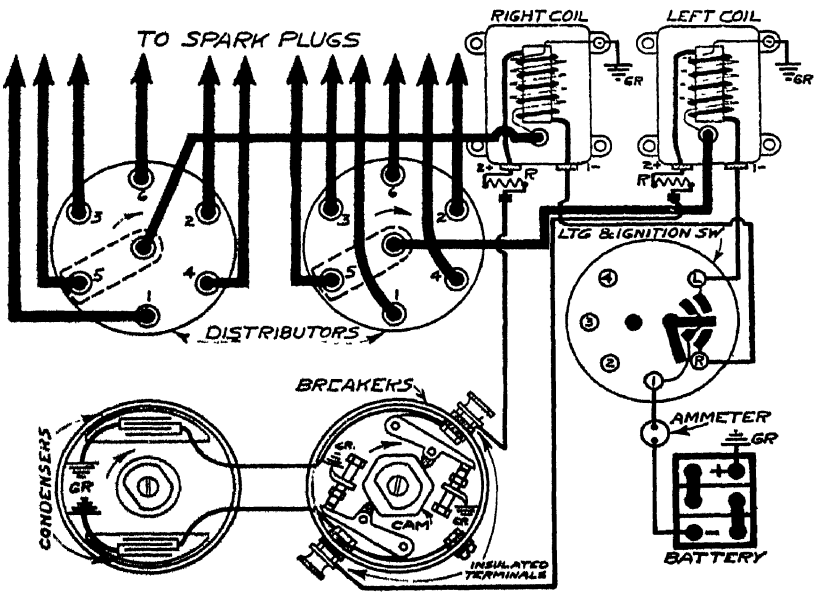


FIG. 180.—Circuit diagram of Delco dual ignition system on Pierce-Arrow.

The ignition switch is so constructed that either or both sets of spark plugs may be operated at will. It is virtually a double system, but the

breakers are timed together so that both spark plugs in the cylinder fire at the same instant. In case of emergency, as with a storage battery in a badly discharged state, this system can be operated as a single system, using one breaker and one set of spark plugs, thereby reducing the ignition-current consumption.

The two distributors, Fig. 179, are operated in time with each other, the distributing rotor F of each being driven at the same speed (namely one-half crankshaft speed), by means of a horizontal shaft and spiral gearing. The unit is also provided with an automatic spark-advance device C, which is located on the lower end of the shaft which carries the breaker cam. This is in the form of a centrifugal-type governor, so designed that an increase in engine speed causes the weights to spread outward, shifting the breaker cam slightly ahead so as to advance the time of the spark with respect to the crankshaft position.

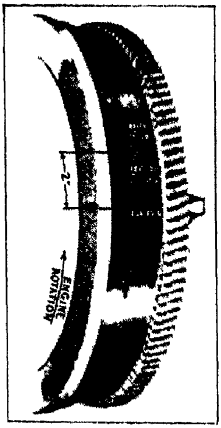


FIG. 181.—Position of flywheel for ignition timing on Pierce-Arrow dual valve six.

A circuit diagram of the system is shown in Fig. 180 Upon tracing the primary circuits, it will be found that the two breakers operate in different circuits, one producing the ignition in one set of plugs, while the other produces ignition in the second set of spark plugs. By a study of the breaker assembly, it will be found that both breakers are operated by the same cam; in fact, the contact arms are located diametrically opposite, so that the opposite cam lobes open both sets of contacts at the same instant.

Adjustment of Breaker Points Important.—Inasmuch as the success of the two-point scheme of ignition is dependent upon the two sparks occurring simultaneously, it is evident that the two breakers must open at exactly the same instant. Therefore, every possible care must be taken to have the breakers timed to open together. A scheme for making this adjustment is taken up in Art. 128 of this section. The breaker points are made of tungsten and each set should be adjusted to open 0.015 in.

Timing Ignition with the Engine.—For timing a double-ignition unit of this type to the engine, the flywheel should first be placed so that the indicator is over the "ignition" mark on the flywheel, as shown in Fig. 181. Great care should be taken to see that the piston of No. 1 cylinder is on the top end of its compression stroke. With the ignition unit disconnected from the engine, and the distributor heads removed, the distributing arms, or rotors, should be set in a position so that each makes contact with distributor terminal No. 1, leading to the spark plugs in No. 1 cylinder.

Then, with the driving shaft in such a position that the breaker points are just ready to open and with the spark lever fully retarded, the driving shaft of the unit should be coupled to the driving flange on the engine. The firing order of the engine is 1-5-3-6-2-4.

124. Delco Ignition System for Cadillac Eight-cylinder Engine. The ignition requirements of the Cadillac eight-cylinder engine

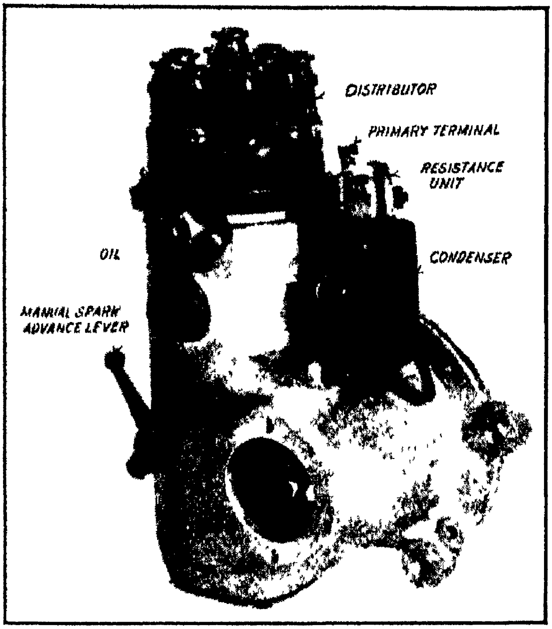


FIG. 182.—Delco ignition unit for Cadillac Eight.

were discussed in Art. 60, page 58. The breaker unit is shown in Fig. 182, while Figs. 183 and 184 show the breaker and circuit

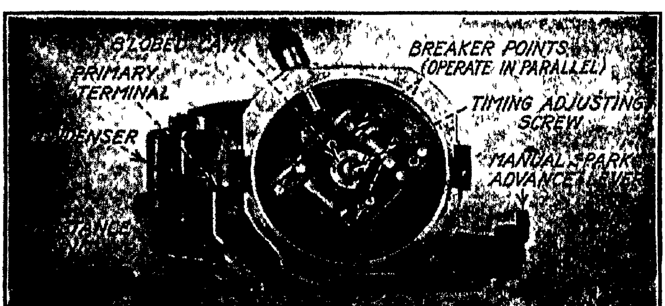


FIG. 183.—Delco breaker mechanism used on Cadillac Eight.

diagram respectively. As will be noted, the two breakers operate diametrically opposite on the same cam, and in parallel with each other in the same circuit in series with a single induction coil.

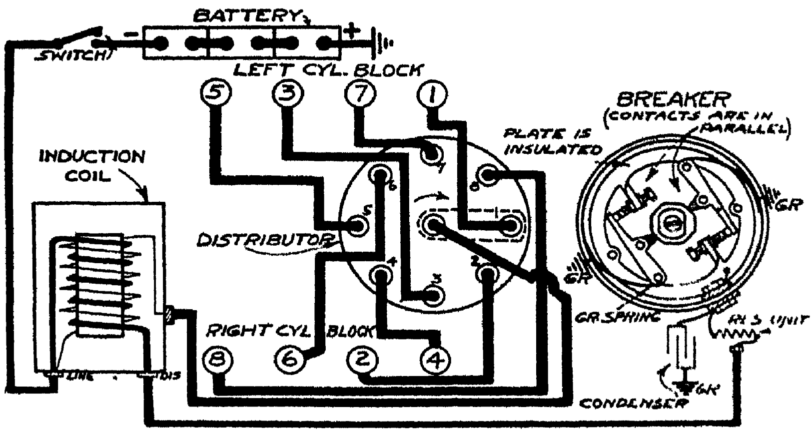


Fig. 184.—Circuit diagram of Delco ignition system on Cadillac Eight.

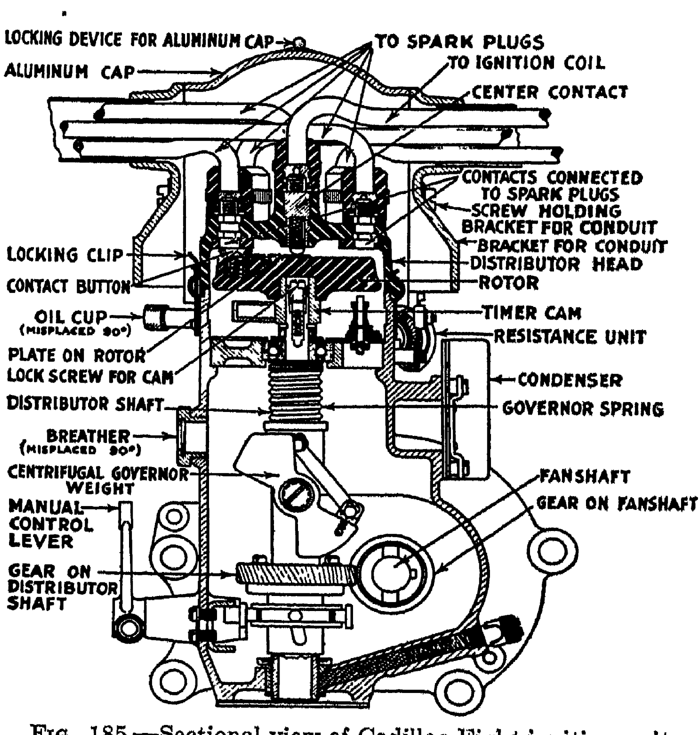


Fig. 185.—Sectional view of Cadillac Eight ignition unit.

The object of this parallel arrangement of breakers is to distribute over two sets of contacts the wear which would normally occur in one set, thereby increasing the life of the contacts.

The effect is lost, however, unless both sets of contacts are adjusted to open at exactly the same instant. The contact opening should be 0 015 to 0 020 in. For synchronizing multiple breakers, see Art. 128, page 169.

The interrupter, the distributor, the condenser, and the automatic spark-advance mechanism are all located in a compact unit mounted on the fanshaft housing and driven by the fanshaft through spiral gears In this

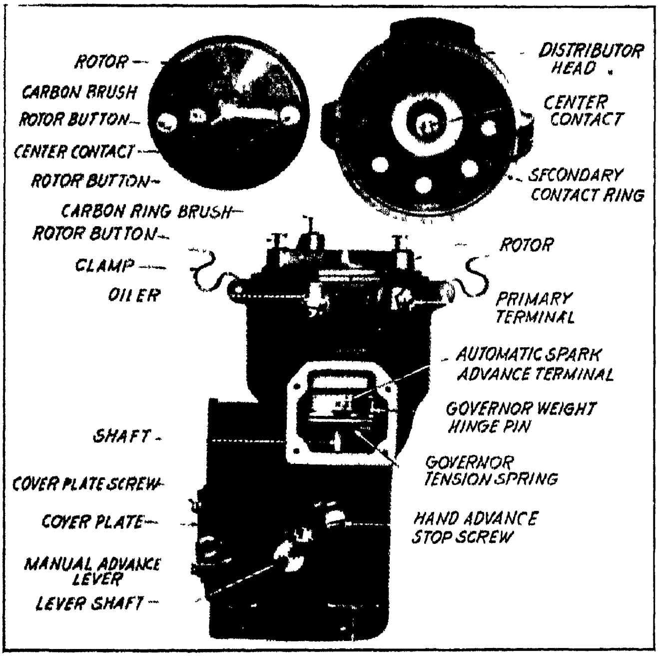


FIG. 186.- Delco ignition unit for Lincoln Eight with distributor head removed The special two contact rotor is shown at upper left.

installation the ignition unit is completely inclosed by a metal container and has metal conduits leading from the unit to each cylinder block to carry the high-tension spark-plug wires. The cover protects the unit from dust and the conduits protect the wires from accidental injury.

Figure 185 is a sectional view of the ignition unit, showing the distributor at the top, the timer or interrupter below, and the automatic spark-advance mechanism at the bottom. The condenser is mounted on the right-hand side of the unit in a water-proof casing. The spark timing is controlled automatically by the automatic spark-advance mechanism, which advances or retards the position of the timer cam relative to the driving shaft as the

engine speed increases or decreases A spark lever at the steering wheel is provided, however, by which the timing may be further advanced or retarded. This spark lever is connected to the manual control lever at the left of the distributor housing.

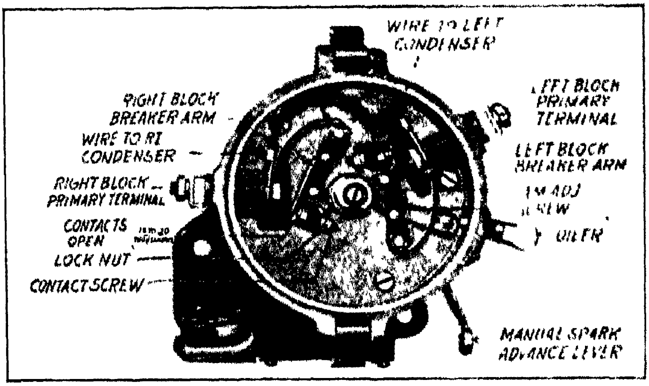


FIG. 187.—Delco breaker for Lincoln Eight 60 deg., V-type engine

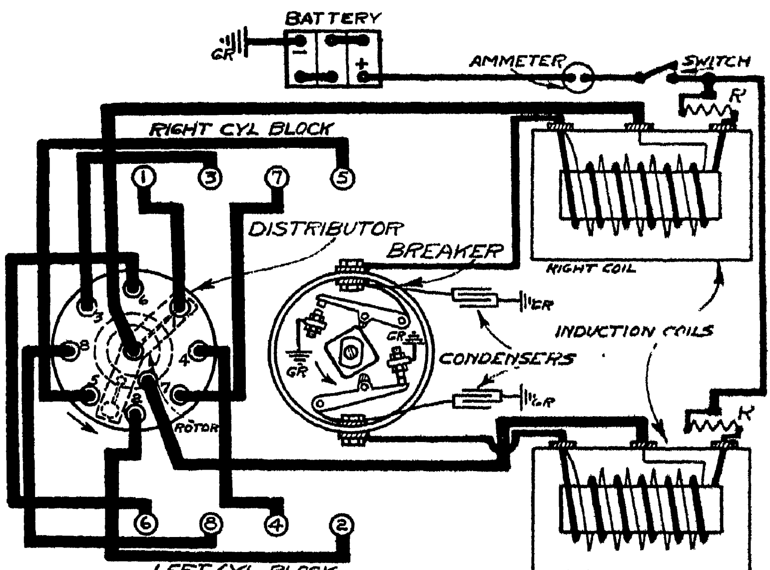


FIG. 188.—Circuit diagram of Delco ignition system on Lincoln Eight.

125. Delco Ignition System for Lincoln Eight-cylinder Engine. In the Lincoln eight-cylinder engine the usual angle of 90 deg. between cylinders, common in V-type eight-cylinder construction,

has been reduced to 60 deg. in an attempt to minimize engine vibration. This means that sparks must occur at unequal intervals of crankshaft travel, namely, 60 and 120 deg. apart, as described in Art. 61, page 61. The ignition unit, therefore, is of special design, in order to provide ignition sparks at these unequal angles.

The external view of the Delco ignition unit for the Lincoln Eight with the distributor head removed is shown in Fig. 186, while the arrangement of the breakers is shown in Fig. 187. It will be noted that the two breakers are arranged to open 30 and 60 deg. apart, respectively, the cam being four-lobed and driven at one-half crankshaft speed The distributor rotor is also specially designed, the circuits through the distributor head being shown in the circuit diagram, Fig. 188. It may be seen from this circuit diagram that two induction coils are used. These operate alternately in conjunction with the two breakers, which open and close alternately in accordance with the crank angles given above.

For completing the high-tension circuits of the two coils with the spark plugs in their proper order of firing, separate high-tension coil terminals are arranged on the distributor head. One terminal connects directly with a carbon contact at the center and the other to a metal ring surrounding the center terminal. As Figs. 186 and 188 show, the distributor rotor carries two buttons at opposite sides. One connects with the center terminal while the other connects with the ring in the distributor head when this is in position.

Since each contact button is insulated from the other, and since they are set so that their angular distance apart is one-half a revolution less one-half the space between the eight distributor terminals (or 22½ deg.), they will make contact alternately. While one distributor button is in contact the other is in the "Off" position, or half way between the segments. Care must be taken to see that both primary and secondary leads from the coils connect with their correct terminals on the distributor The breaker points should be adjusted to open 0.015 in. The firing order is 1-2-4-3 in each block.

126. Delco Ignition System for Packard Twelve-cylinder Engine.—The ignition requirements for the Packard twelve-cylinder engine were described in Art. 65. The Delco ignition unit and breaker are shown in Fig. 189 and the circuit diagram in Fig. 190.

The two breakers operate in separate circuits, each in conjunction with its own induction coil, the secondary circuits being completed through two separate six-cylinder-type distributors, one distributor for the left cylinder block and the other for the right cylinder block. The breaker cam is of the three-lobe type and rotates at engine speed, making three breaks per revolution in each primary circuit, thus producing a total of six sparks per revolu-

tion of the crankshaft, three in one cylinder block and three in the other. The two distributors are below the breaker box, one on either side. They are driven by spiral gears from and at one-half the speed of the vertical shaft which carries the breaker cam.

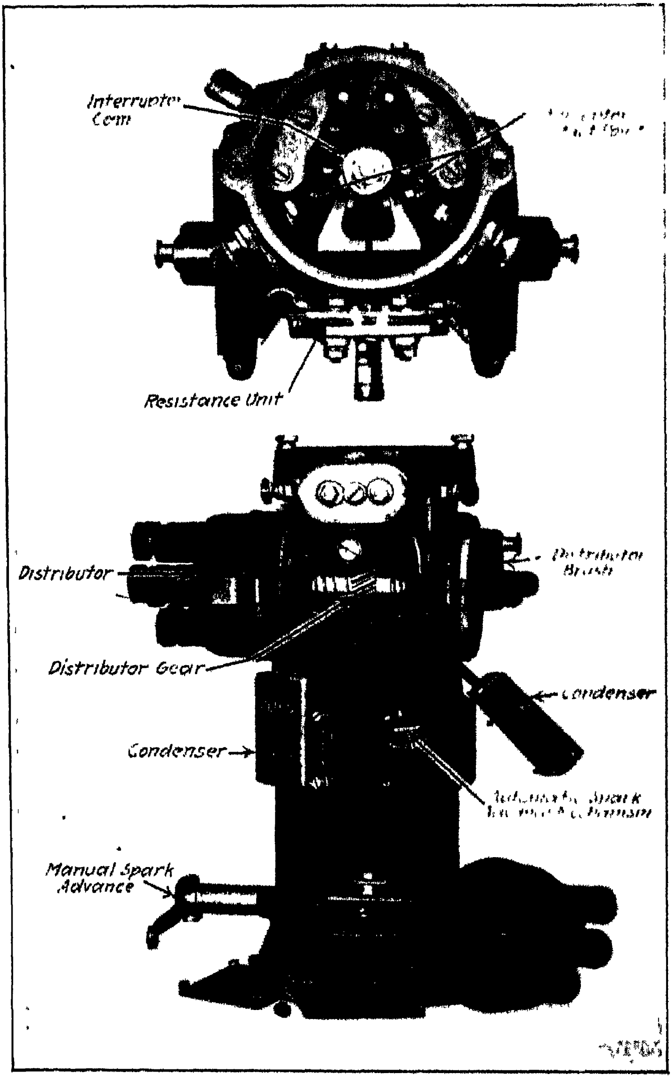


FIG. 189.—Delco ignition unit on Packard Twin Six.

Two condensers, one for each pair of primary contact points, are mounted on the ignition-unit housing. These condensers serve as cover plates for openings in the housing through which the automatic spark-advance mecha-

nism in the lower part of the case may be examined. The ignition unit is mounted between the blocks at the front of the engine and is driven by spiral gears from the camshaft.

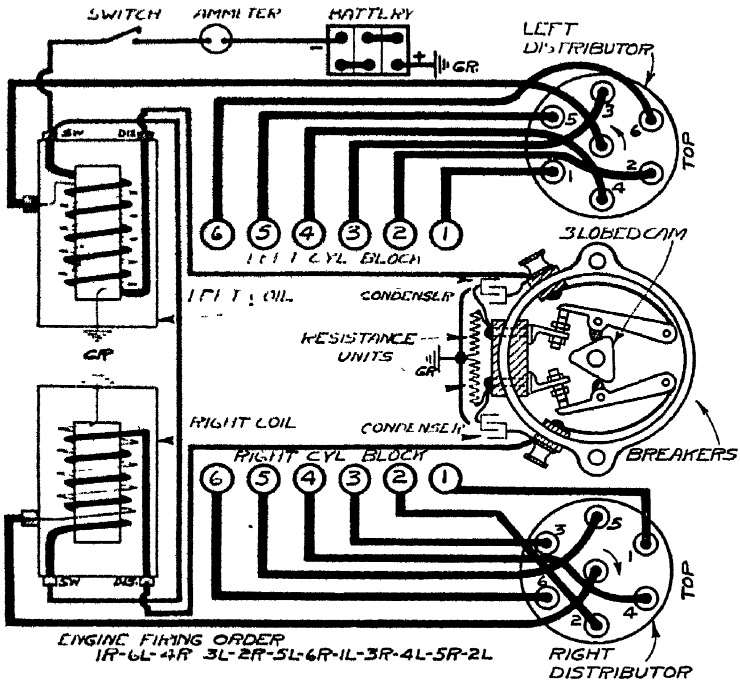


FIG. 190. Circuit diagram of Delco ignition system on Packard Twin Six

127. Delco Ignition System for Liberty Twelve-cylinder Aircraft Engine.—At the beginning of the World War, when the Liberty twelve-cylinder aircraft engine was developed, the Delco battery ignition system, specially designed for this engine, was adopted as standard. The reasons for its adoption include the following:

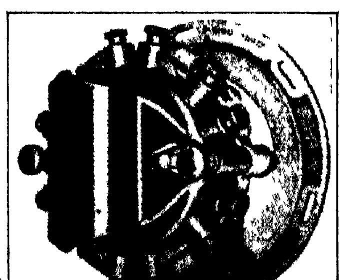


FIG. 191.—Delco distributor unit for Liberty Twelve aircraft engine.

1. There was no magneto on the market at that time capable of producing suitable ignition at the unequal angles of 45 and 75 deg.—at least, that could be produced in sufficient quantities to meet the demands.

2. Battery ignition provides a good spark for starting, which is highly desirable in high-compression aircraft engines. As a

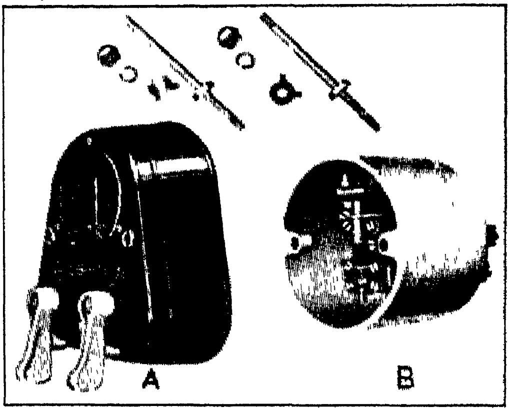


FIG. 192.—Delco control switch and voltage regulator for Liberty Twelve aircraft engine. (*A*) Switch. (*B*) Regulator.

matter of fact, the one aim in the Liberty twelve-cylinder Delco system was to obtain ignition sparks of the same intensity at the

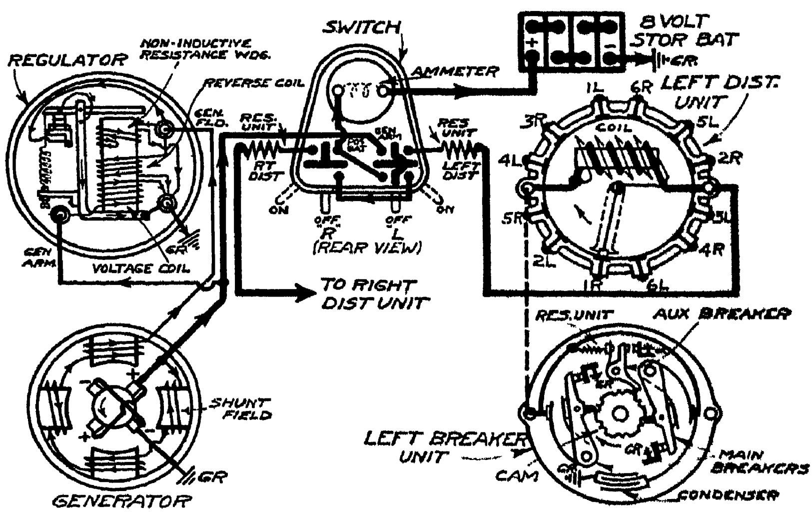


FIG. 193.—Circuit diagram of Delco ignition system for Liberty Twelve aircraft engine.

required irregular intervals, and to obtain a simultaneous occurrence of the duplicate sparks (two plugs being used in each

cylinder), not only at the proper firing angle, but at all speeds. The Liberty aircraft engine, showing the breaker and distributor units, is shown in Fig. 81, while Figs. 191 and 192 show the distributor unit (left) and control switch respectively.

The Liberty Twelve ignition system consists mainly of a low-voltage generator operating in conjunction with an 8-volt storage battery; a voltage regulator, Fig. 192*B*, for maintaining the generator voltage at 10 to 10½ volts; two duplicate distributor units mounted directly upon the camshaft housings of the engine and operated through the direct drive of the camshafts; a switch, Fig. 192*A*, through which the current may be directed to the two distributor units; and the necessary wiring, terminals, and spark plugs Each cylinder has two spark plugs, connected to the two distributors so that the right-hand distributor fires the distributor-end plugs and the left-hand distributor fires the propeller-end plugs of each of the twelve cylinders, thus providing a duplicate system to insure against failure of ignition in service.

A circuit diagram of the system is shown in Fig. 193. The circuit details of one distributor unit only are given, as the units are identical in this respect The two distributors should be synchronized so that both sets of breakers open simultaneously, thus producing sparks at the same instant at both sets of plugs.

Note—Only the ignition circuits will be discussed at this time, since the study of the generator and regulator is beyond the scope of this section and will be taken up in detail later It is sufficient to note, however, that when both switches are turned "On" the circuit between generator and battery is complete and at all speeds above 500 r p m the output from the generator is sufficient to supply ignition even with the battery disconnected At all speeds over 650 r p m , the generator output is sufficient to supply ignition and also to charge the battery.

Operation of the Switch.—By a study of the circuits, Fig 193, it will be found that by turning on one or both switches, single or double ignition may be used. Double ignition should be used at all times when running above 650 r p m., at which time the generator will supply all the current used by the ignition and keep the battery charged.

As the generator does not produce sufficient voltage at less than 650 r p.m. engine speed, the operation of both switches at less than this speed causes the battery to discharge wastefully through the generator. No automatic cutout has been provided to prevent this, thereby somewhat simplifying the system. The operation is as follows: The engine must be started, using one switch lever only—either one will do, the right-hand *R* switch lever causes the right-hand distributor to furnish ignition, while the left-hand *L* switch lever causes the left-hand distributor to furnish ignition. After the engine is started, the speed should be increased to 650 r.p.m. or more, and both switch levers turned to the "On" position.

Note.—The engine should not be started with both switch levers "On," as it not only takes double the amount of battery current for ignition, but causes a heavy discharge through the generator, causing the battery voltage to drop, thereby making starting hard

It also drains the battery excessively and reduces the available emergency supply, causing the generator to charge at a high rate at flying speed and so overload the generator.

Should it be desirable to run the engine idle at less than 650 r p m, only one switch lever should be used Under this operation, the battery ammeter will show a normal discharge of not over 3 amp

The High-tension Distributor.—The high-tension distributor unit includes not only the usual distributor for directing the high-tension current to the various spark-plug wire terminals, but also the induction coil which is mounted in the Bakelite distributor head—breaker, and condenser The circuits of the coil and breakers are shown in Fig. 193. The molded Bakelite head containing the ignition cell fits upon the aluminum breaker base and housing, and forms its circuits by means of two studs engaged by thumb-screws on the head. The head is, in addition, secured by spring clamps

The high-tension terminal of the coil is a carbon button extending through the under side of the head, and, when in position on the breaker mechanism, makes contact with a flat spring on the high-tension rotor. The rotor turns as a unit with the cam which actuates the breaker mechanism. This fixes the relation of the cam lobes and secondary distribution, insuring that they bear exact relation to each other at all times. The rotor carries a soft-carbon brush which makes a wiping contact upon a hard-rubber track around the outer rim of the distributor head. The high-tension distributor terminals are spaced at the unequal angles of 22½ and 37½ deg. in order that the engine may fire at the crank angles of 45 and 75 deg. (The breaker and distributor unit is driven at cam speed, or one-half the speed of the crankshaft.)

Breaker Mechanism.—There are two main breakers, which operate in parallel, in each distributor unit. The object of this is to distribute the contact wear over twice the contact area, thereby increasing the life of the points. These main breakers operate diagonally opposite on the cam, and should be adjusted very carefully to open at the same instant and the same amount. Proper adjustment can be obtained by shifting and adjusting the bracket upon which the arms are pivoted. The main contact arms are provided with special rubber cushions, vulcanized into place under the springs. These prevent chattering, which would cause poor contact at high speed. The cam has 12 lobes spaced 22½ and 37½ deg. apart to produce sparks in accordance with the distributor design and engine requirements. The condenser is connected in parallel with both sets of breaker points, one terminal connecting to the insulated side, while the other is grounded.

Auxiliary Contact Arm.—In addition to the two main breakers there is a third contact device called the *auxiliary breaker*. This is used as a safety device and is electrically connected in parallel with the two main breakers. It is arranged to open and close a few degrees before the main contacts, when operating in a clockwise or normal direction of rotation, thus taking no part in the interruption of the current. If the engine is rocked backwards, however, such as it might accidentally be when cranking with the propeller, the auxiliary contacts open last (a few degrees after the main contacts). The auxiliary breaker is in series with a resistance unit which will reduce

the current flowing to such a degree by the time the contacts open that the magnetic flux in the coil is so weakened that it will not produce a voltage sufficiently high to jump the spark-plug gaps. Furthermore, the resistance unit and auxiliary contacts, being in circuit when the main contacts open, form a short circuit for the condenser, thus preventing the induction of high voltage. The function of the auxiliary breaker is, therefore, to prevent the engine from firing backwards.

Contact Adjustment.—The contacts of both the main and the auxiliary breakers should be adjusted to the same opening of 0.010 to 0.015 in. when contacts are fully open and synchronized to open at the same time. The spring tension on the main contacts should be 26 to 30 oz. and 16 to 20 oz. on the auxiliary contacts. The springs are slotted to secure and to adjust the necessary tension.

Timing Range.—By rotating the entire breaker mechanism against or with the direction of rotation, the cam operates the breakers at an earlier or later period in relation to the pistons. The speed of the engine, of course, governs the amount of advance necessary. On the Liberty engine a 30-deg. advance and a 10-deg. retard are provided.

128. Timing of Multiple Breakers.—Inasmuch as there are two styles of multiple breakers, one in which the two breakers operate in parallel, as illustrated in Fig. 184, and the other where the breakers operate in separate circuits, as shown in Fig. 180, naturally problems will arise when the service man comes to timing the two sets of contact points so as to open at the same instant.

Probably the best scheme to be used in adjusting the breakers to open simultaneously is that shown in Fig. 194. This shows a handy test set consisting of a block of wood with two small 6-volt lamps provided with suitable test leads. The terminals *A* and *B* are each made of a thin piece of fiber 1½ by 1 in. in size, one side of each being covered by a thin piece of brass or copper to serve as a contact and to which the leads from the lamps are connected.

The same test set can be used in adjusting both types of breakers, as follows: The first type, in which the two sets of timing contacts are connected in parallel, will be referred to as type I, and the other, in which the two sets of contacts are in separate primary circuits, as type II.

When used with distributors of type I, each of the terminals *A* and *B* are slipped between the contact-arm springs and the distributor housing with the metal side of the terminal in contact with the spring, as in Fig. 194*A*. Lead *E* is then connected to "ground." Current for testing is obtained from the storage battery on the car by placing the ignition switch lever in the "On" position. (During this operation it will be well to place a piece of cardboard beneath one of the generator brushes in the Delco generators not equipped with a cutout relay, in order to prevent a flow of current through

the generator windings.) When used with type H distributors, the notche in the ends of the terminals A and B permit them to be readily connected to the two terminals on the distributor. The lead E may be connected either to a 6-volt storage battery or to a group of four dry cells in series, as in Fig. 194B.

The time of separation of each set of contact points will be indicated by the lamp in the circuit. When both lamps go out at practically the same instant, the contacts are properly synchronized. Both sets of contacts should be adjusted to open at exactly the same amount, usually 0.015 or 0.020 in.

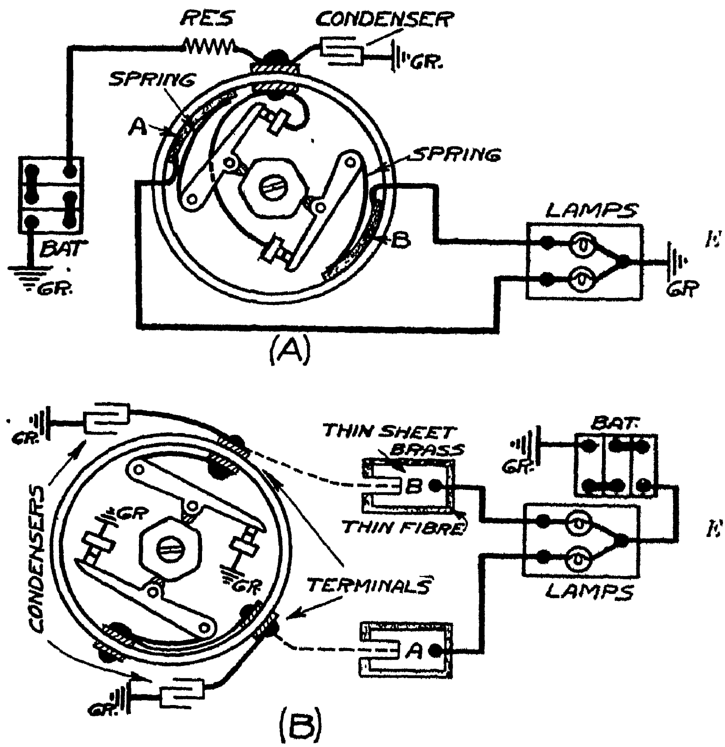


FIG. 194.—Methods of synchronizing multiple breakers. (A) Breakers in parallel. (B) Breakers in separate circuits.

129. Ignition Timing on Eight- or Twelve-cylinder Engines. The timing of the ignition system on an eight- or twelve-cylinder engine is very little different from the timing of a four- or six-cylinder ignition system, as explained in Art. 121. The same method is employed in each case. The firing order of the engine should be determined by the methods described in Sec. III. The

next step is to set piston No. 1 of the right cylinder block on the firing position, which is generally zero to 5 deg. (on the flywheel) past upper dead center on the working or expansion stroke. Then with the spark lever fully retarded, the screw holding the breaker cam (if such is provided) should be loosened and the breaker cam turned until the breaker points are just opening and the distributor arm is on the distributor segment connecting with the high-tension cable leading to the spark plug in cylinder No. 1 in the right cylinder block. The breaker cam should be tightened in this position and the remaining high-tension cables connected to the plugs in the cylinders according to the firing order previously determined, going around the distributor in the direction of rotation of the distributor arm.

In cases where the cam itself is not adjustable, the proper ignition timing can usually be made by means of an adjustment at either the driving coupling or pinion. On the Packard, the timing adjustment is made at the lower end of the ignition driveshaft.

SECTION VIII

LOW-TENSION MAGNETOS

Although the low-tension magneto is not used much at the present time in automobile ignition, at least on the newer cars, it is quite essential that the auto electrician or mechanic understand it thoroughly in order to have the proper foundation for a study of high-tension magneto ignition. Also many of the older cars have low-tension magneto systems. These may seem quite complicated if the mechanic does not understand them.

FIG. 195. The Remy low-tension magneto, model RL.

130. Magneto Classification.—The magneto, a typical example of which is shown in Fig. 195, is an electric generator used for ignition purposes. It generates electricity by means of electromagnetic induction, the magnetic field being supplied by permanent steel magnets. A low-tension magneto is one in which the current generated is of low voltage, requiring an induction coil to transform it to a high voltage suitable for jump-spark ignition.

The essential parts of a low-tension magneto ignition system are: (1) permanent magnets for producing the magnetic field; (2) the generating element in the form of either a rotating armature or a rotor; (3) a transformer coil for transforming the current

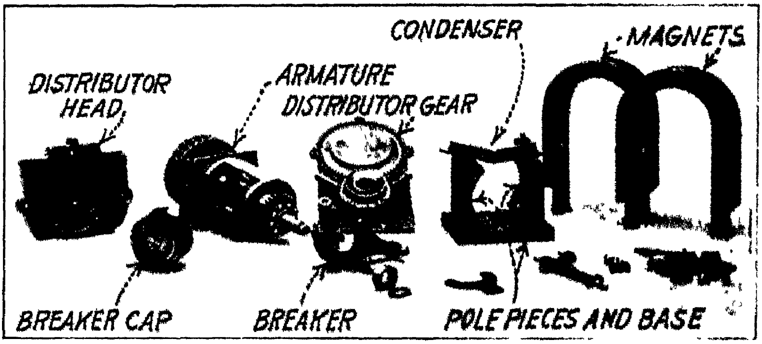


FIG. 196.—Principal parts of typical armature type magneto (Splitdorf)

from low voltage to high voltage, suitable for jump-spark ignition; (4) a breaker or interrupter for making and breaking the primary circuit at the proper time with respect to the engine crankshaft and pistons; (5) a condenser for protecting the breaker

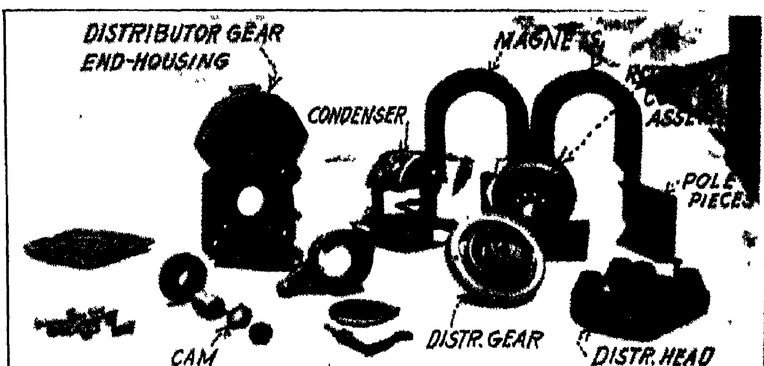


FIG. 197.—Principal parts of typical inductor type magneto (Remy RL).

contact points against arcing and pitting; and (6) a distributor for directing the high-tension current induced by the transformer or induction coil to the various spark plugs in their proper order of firing.

The magneto may be built in two general forms, according to the method employed for generating the current, namely, *armature-wound*, or H-type (sometimes called *shuttle-wound*, since it resembles a weaver's shuttle), and the *inductor type*. In the armature-wound type, the current is generated by a winding revolving in and cutting the magnetic field, while in the inductor type the winding is stationary, the current being generated by the magnetic field cutting the winding, that is, a current is generated by the reversal of the magnetism through the coil and the cutting of the winding by the magnetic lines of force. The component parts of typical low-tension magnetos of the armature-wound and inductor types are shown in Figs. 196 and 197 respectively.

The magneto may also be classified either as high or as low tension, according to the voltage of the current which it generates. Both the high- and the low-tension magnetos may be constructed on either the armature-wound or the inductor principle.

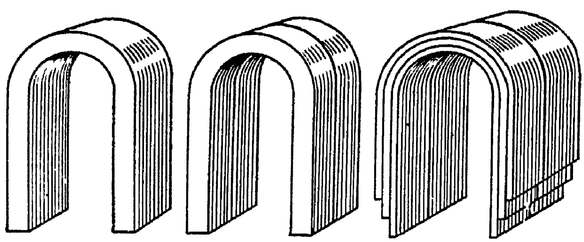


FIG. 198 —Types of magneto magnets

131. Types of Magneto Magnets.—A piece of magnetized steel shows greater magnetic strength at the ends than in the middle of the bar. As explained in Sec II these ends are called the magnet poles. It was also pointed out that around a bar magnet there exists a magnetic field which flows from the north to the south poles.

Since in the magneto the current is generated by the winding either cutting or being cut by the magnetic lines of force, the amount of current produced will be in proportion to the speed at which the magnetic lines are cut. It is evident, then, that the strength of the magnetic field should be as great as possible to insure sufficient current for ignition purposes being generated at low rotative speeds. It is, therefore, evident that the magnets

used in magneto construction are of the U-shape in order to bring the north and south poles close together, so as to intensify the field strength cut by the armature. Types of magneto magnets are shown in Fig. 198.

In some magnetos more than one magnet is used in order to produce a strong magnetic field. In such cases the magnets

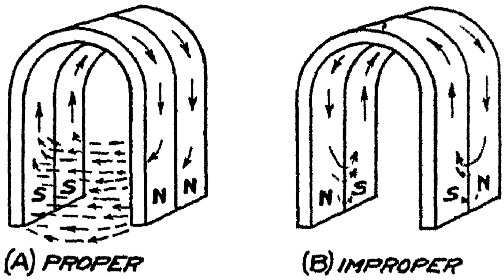


FIG. 199—Proper and improper arrangement of magneto magnets, the arrows showing path of magnetism.

should be arranged with the north poles together and the south poles together, so that both magnets act as one in producing a strong magnetic field. The difference between the two poles can be determined by first placing the like poles and then the

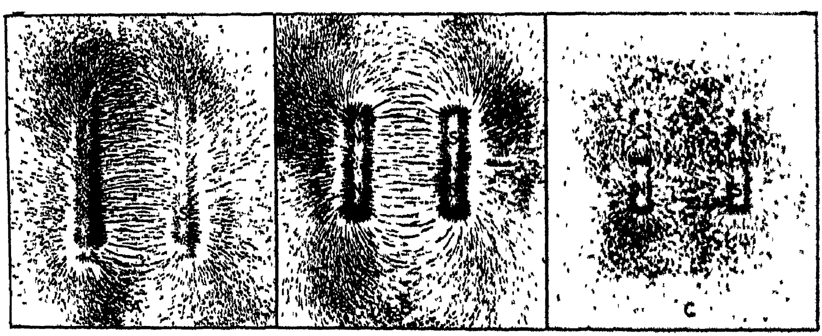


FIG. 200.—Arrangement of iron filings when sprinkled on card-board held over magneto magnets. (A) Magnet laid on side. (B) With magnets properly assembled. (C) Magnets improperly assembled.

unlike poles of two magnets together. It will be found that the like poles repel each other and the unlike poles attract each other.

Where two or more magnets are used on a magneto, care must be taken to get all the north poles together and all the south poles together, since one magnet reversed will short-circuit the magnetic field through the magnets

instead of allowing it to pass through the armature, thus preventing the magneto from generating current. An easy way to make sure of proper magnet installation is to lay the magnets together so that the poles will repel each other, before sliding them into place on the magneto. Figure 199 shows the proper and improper arrangement of magnets. In Fig. 199*B* the arrows indicate that the path of the magnetism is completed through the magnets. This is further illustrated in Fig. 200 by the formation of the iron filings. *B* and *C* in Fig. 200 show proper and improper arrangements of the magnets respectively.

132. Composition of Magneto Magnets.—Since the magnets used in magneto construction must be of the permanent type, that is, must hold their magnetic strength indefinitely, it is important that the proper quality of steel be used. In the older types of magnets, for example those used in the manufacture of many low-tension magnetos, nickel steel hardened to a high degree was used a great deal. At the present time in high-tension magneto construction, tungsten steel and chromium steel are generally used. It has been found that the quality of the magnet does not depend so much on the hardness as upon the content of the steel. Of the two materials, tungsten steel is more commonly used.

The name *tungsten steel* is derived from the fact that from 3 to 5 per cent tungsten is mixed with the steel to give it its special qualities as a magnet. In this connection it might be remembered that tungsten itself is a non-magnetic material, but for some reason unknown when mixed with steel at the proper proportion, it gives that steel wonderful properties of retaining magnetism.

Pull of Magnets.—The usual magnet found in high-tension magneto service should exert a pull of 25 to 35 lb , while in the older type magnets used on low-tension magnetos the magnetic pull of the magnet should be able to sustain a weight of at least 15 lb. in order to give satisfactory service.

133. Generation of Current in the Armature.—Figure 201 shows typical armatures used in low-tension magneto construction. In Fig. 201*A* is shown the collector-ring type, while Fig. 201*B* shows the contact-button type. It may be seen that a winding is wound on a soft-iron core, the entire unit being supported at each end by bearings, so that it rotates freely between the pole pieces, Fig. 202, and causes the winding to revolve in the magnetic field.

Successive armature positions during one rotation of the armature are shown in Fig. 203. It will be seen that the winding cuts the magnetic field first in one direction, then in another, causing an alternating voltage to be generated.

In the actual magneto armature, instead of having only one turn of wire, a great many turns wound in the shape of a coil

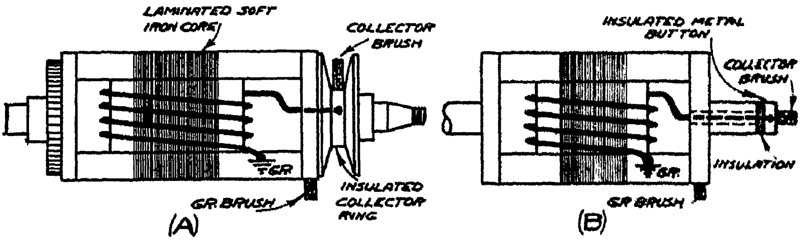


FIG 201.—Types of low-tension magneto armatures

around laminated iron are used. By using laminations, the core strength of the magnetism between the poles of the magnet is thereby increased. This, in turn, increases the number of lines of force to be cut by the winding. Laminating the core also prevents any heating from eddy currents.

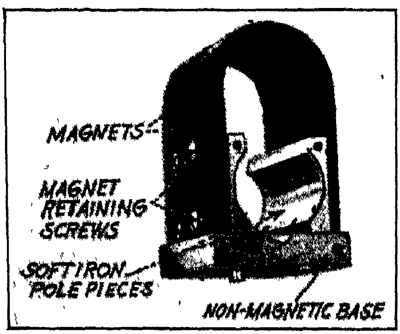


FIG. 202.—Magneto magnets and pole pieces assembled.

134. Current Wave from Typical Shuttle-wound Armature. It will be found by reference to Fig. 203 that the magnetic field flows through the armature core first in one direction, then in the other, as the armature rotates. With the armature in an upright position, the magnetic field can pass through the armature sides without flowing through the winding, but, as the armature advances in its direction of rotation, when the corner of the armature leaves the corner of the pole piece, the only iron path which the magnetism can follow is through the coil in a reversed direction.

The cutting of the magnetic lines of force by the coil of wire produces an induced alternating voltage in it which will vary in value (during one revolution), as illustrated in Fig. 204. The

part of the curve above the horizontal line illustrates graphically the voltage produced in one direction, while that below the horizontal line illustrates the voltage set up in the reverse direction. Both halves of the curve are identical in proportion.

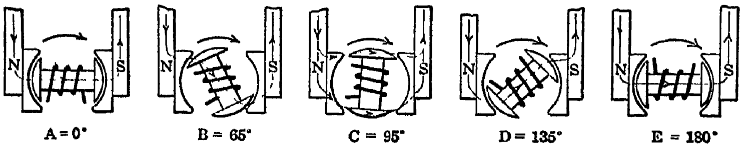


FIG. 203.—Successive armature positions in magneto with shuttle or H-type armature

In case the armature winding should be short-circuited with an alternating-current ammeter connected in the circuit, a current wave would be produced during one revolution of the armature of the proportion illustrated in Fig. 205.

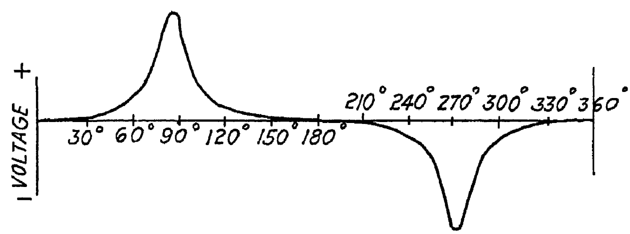


FIG. 204.—Curve illustrating voltage produced by typical low-tension magneto armature during one revolution

Figure 203 shows the positions of the armature corresponding to the points A, B, C, D, and E of Fig. 205. In position A,

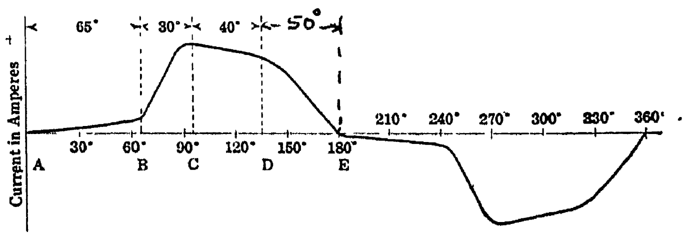


FIG. 205.—Typical curve of current produced in shuttle type armature during one revolution.

the magnetic flux is passing through the armature in one direction, while in position E, after turning 180 deg. the flux is in the other direction, since the armature has turned completely over. During

the remainder of the revolution from position *E* around to position *A*, the current generated will be opposite in direction to that generated during the first half of the revolution. The current generated during the first half of the revolution is shown in Fig. 205 by the height of the curve above the horizontal line, while that generated during the second half is shown below the line.

It will be noted from a study of this curve, that the stronger electrical impulse is obtained when the armature is in approximately a vertical position, as illustrated by *C*, Fig. 203, since this is the point at which the most magnetic lines of force per second are being cut, due to the rapid changing of the path of the magnetic field through the armature.

The exact positions of the armature at which the strongest electrical impulses can be obtained and also the exact shape of the current wave depend largely upon the shape of the pole pieces and the characteristics of the armature core as well as upon the speed of armature rotation and the strength of the magnets. In fact, any change in one of these factors will produce a change in the electrical pressure at the terminals of the armature winding.

135. Magneto Speeds.—Most magnetos which are run at variable speeds are constructed so that a strong current can be produced throughout a considerable range of position of the armature with respect to the pole pieces. This is done to allow for the advance and the retard of ignition relative to the position of the pistons, as well as to allow for the lag of the current in the armature with regard to the position of the armature at the instant of maximum impulse or voltage. The current lag for speeds encountered in ordinary practice is small, so that, in general, the positions of the armature for the maximum current are as indicated in Figs. 203 and 205.

It is evident from the current-wave diagram of Fig. 205 that, whatever the system of ignition with which a low-tension magneto is used, the best spark will be produced only during the angle of rotation in which the current generated is at or near its maximum. When the armature is in position *C*, Fig. 203, the current is at its maximum and the spark is strongest. As the armature rotates from position *C* to *D*, the curve, Fig. 205, is near its maximum height; hence, during this period the current produced is most favorable for ignition purposes. Position *C* would correspond to extreme advance and *D* to extreme retard for this magneto, giving a spark range of about 40 deg. of armature rotation. It is evident from the shape of the curve that a position of advance beyond *C* or retard beyond *D* would give a spark too weak for ignition purposes, or no spark at all. This shows the necessity of having an alternating-current magneto either chain- or gear-

driven from the engine shaft, so that the armature will always be in the proper position with relation to the engine pistons. The curve of Fig. 205 also shows that there are two points in a revolution in this type of armature during which a spark can be obtained, namely, between *C* and *D* as just mentioned and at a similar position 180 deg. later, when the current is in the reverse direction. Thus, a magneto with an H-type or shuttle-wound armature, such as ordinarily used for automobile ignition, gives two sparks per revolution of its armature. Because of this, the armature speed of a magneto must have a definite relation to the number of cylinders of the engine. In a four-cylinder four-cycle engine the armature must revolve at crankshaft speed in order to produce four sparks during two revolutions of the engine crankshaft, and in a six-cylinder engine the armature must make three revolutions during two revolutions of the crankshaft, or it must turn at one and one-half times crankshaft speed.

136. The Inductor-type Magneto.—The winding in the inductor-type magneto is stationary. The armature is replaced usually by a soft-iron rotor, which is designed to direct the magnetic flow through the winding of the coil, first in one direction, then in the other.

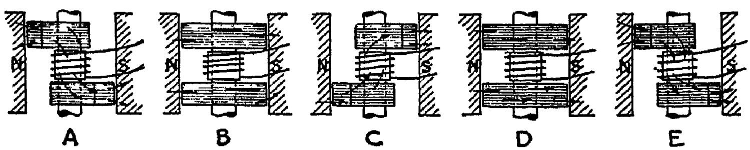


FIG. 206.—Path of magnetic flux through Remy inductor during one revolution

The principle of the inductor-type magneto is illustrated in Fig. 206 which shows the construction used in the Remy Model RL magneto. The rotor, during one revolution, causes one complete reversal of the magnetism through the coil; consequently, the current produced in this type of magneto is also alternating in direction, just as it is in the armature-wound type.

137. Comparison of Armature-wound and Inductor-type Magnetos.—On account of the difference in construction of the two types of magnetos, different methods of conducting current from the coil winding are necessary. In the armature type, because the winding rotates, it is necessary to provide either special terminal contact buttons or slip rings, as in Fig. 201, the contact being made by insulated brushes in order to carry the current from the coil while it is rotating. In order to simplify the construction as much as possible, one slip ring or terminal

contact button only is used, this being connected to one end of the winding, while the other end of the winding is grounded to the armature core. The core, in turn, is grounded either through the bearing or grounding brush, which makes positive ground connections between the rotating armature and the frame of the magneto.

It is essential that the grounding brush make a good connection, since, if it does not the current must flow through the bearings. This is not desirable, particularly with ball bearings, because oil and grease are poor conductors and any slight sparking that might occur in the bearings will cause carbonizing of the oil and pitting of the bearings, a condition which may wreck the entire magneto due to excessive cutting and wearing of the bearings and improper alignment of the armature.

Brushes and slip rings are not required in the inductor-type magneto since the coil is stationary and the connections can be made directly to the insulated terminal on the magneto frame or to the ground—as the system is usually grounded. Thus, it will be seen that, in the armature-type magneto, special brushes and collector rings are necessary for handling the current, while in the inductor type these are unnecessary and a simpler construction is permitted.

Although there are a number of different designs of both the armature and the inductor-type magnetos, the principles involved in each are practically the same.

138. Magneto Breakers.—The breakers employed in low-tension magneto ignition are very similar in construction to those of the closed-circuit type used in battery ignition. The breaker is usually mounted at one end of the armature shaft. The cam that operates the breaker is attached to and rotates with the armature shaft, as in Fig. 207. In the usual type of magneto, in which two current waves are obtained in one revolution the cam will have two lobes, causing the breaker contacts to open twice during each revolution. The point of contact opening must, of course, be timed with the armature.

The breaker housing, in the case of magnetos for automobile use where variable ignition is required, is designed so that it can be shifted around the cam so as either to advance or to retard the spark as necessary. In order to retard ignition, the breaker

housing is shifted in the direction of armature rotation, and to advance the ignition, the housing is shifted against the direction of armature rotation, because shifting the housing against the movement of the cam will cause the contacts to open earlier with respect to crankshaft position.

Contact Points.—The contact points used in magneto breakers must be of platinum in order to withstand the intense heat to which they are subjected in high-speed service. Many materials have been tried for magneto points, but none has been found so far to take the place of platinum. The platinum is usually alloyed with 20 per cent iridium to give it hardness.

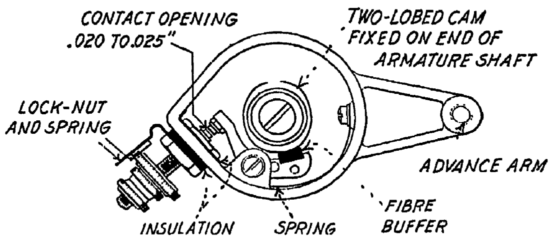


FIG. 207.—Typical breaker and cam arrangement on low-tension magneto (Remy.)

139. The High-tension Distributor.—Since the armature generates only current of a low voltage, the high-tension current for operating the spark plugs must be produced by an induction coil, utilizing the current produced by the armature for providing the primary ignition current.

As in the battery type of ignition system, the distributor is necessary for directing the high-tension current to the various spark plugs in their proper order of firing. In the case of low-tension magneto ignition, a distributor is usually mounted on one end of the magneto, the distributing rotor being driven by means of a gear at a definite speed in time with the armature or rotor.

The distributor on any magneto is similar in general characteristics to that of the battery-ignition type, inasmuch as some are of the wipe-contact type, while others are of the gap type. The distributor terminal segments or *sectors*, however, are usually somewhat longer in the magneto distributor, so as to provide for spark advance and retard and since the magneto spark is usually of longer duration than in the battery-type system.

Since the armature provides two ignition sparks per revolution, and since the distributor must connect with all spark plugs during each revolution, thus it will be seen that a definite gear ratio must be arranged for between the armature or rotor and the distributor. In the two-pole magneto (the kind so far considered), delivering two sparks per revolution, the gear ratio between distributor and armature on different four-cycle engines will be as follows:

For four-cylinder engine, distributor speed is one-half armature speed.

For six-cylinder engine (in which the armature must provide three ignition sparks per revolution of the crankshaft, or run 1½ times crankshaft speed), the distributor speed will be one-third of the armature speed.

Note.—It should be remembered that in all cases the distributor speed is one-half the crankshaft speed.

140. Timing of Magneto Parts.—The magneto must be timed so that all of its parts work in proper relation to each other. This is called *internal timing.* Since the breaker points must open at a definite moment relative to armature position (as the current flowing varies in value with armature position), it is necessary that the cam which operates the breaker be keyed, or otherwise fixed, with respect to the armature shaft. And, as the best ignition spark is obtained if the contacts open when the engine is operating at high speed, the time of contact opening should be such as to interrupt the primary circuit when the current is at its maximum value with the breaker in full advance position.

In most magnetos the maximum current is generated when the corner of the armature has left the corner of the pole piece approximately $\frac{1}{16}$ in., but this may vary with some types of magnetos. If the primary circuit is broken when the current is at its maximum, with the breaker fully advanced, naturally the current will be falling in value when the contacts open with the breaker in a retarded position. This means that a much better spark will be obtained with the breaker in full advance than in full retard at the same relative speeds.

It is important that the distributor be operated in time with the armature shaft. In order to set it correctly, a simple rule which can be followed in most cases is that *the distributor contact arm should be just making contact on the sector at the moment the breaker points open, with the spark-advance lever in full advance position.* This means that the distributor contact will be leaving the same segment when the spark occurs with the breaker fully retarded. Ordinarily manufacturers of magnetos mark the

armature gear and the distributor gear with small punch marks for the purpose of matching the gear teeth properly. Other markings, such as the letters "R" and "L," meaning *right-* and *left-*hand rotation, "C" and "A," meaning *clockwise* and *anti-clockwise*, are also commonly used. In considering the direction of rotation of a magneto, the operator must always view it from the driving end.

141. Principles of the Low-tension Magneto—Interrupted Primary Type.—The operation of the low-tension magneto ignition system, in which the armature, the breaker, and the transformer coil are all in series, known as the *interrupted-primary* type, is very similar to that of an ordinary battery ignition system using a breaker and a non-vibrating coil. The mechanical interrupter or breaker for the primary low-tension current and the distributor for the high-tension current are provided on the end of the magneto, while the magneto armature and winding supplies the low-tension current in place of the battery. A simplified diagram of this type of system is shown in Fig. 208. A magneto with a shuttle-wound or H-type armature is shown, although a magneto of the inductor type could be used as well. One end of the armature winding is grounded to the metal of the armature, as is usual in magneto construction. The primary current is collected from one end of the winding by a collector ring and brush which are not shown. The interrupter and the cam are shown separately, but these are always mounted on the magneto shaft, so that the time of opening the circuit coincides with the period of greatest current flow in the armature winding.

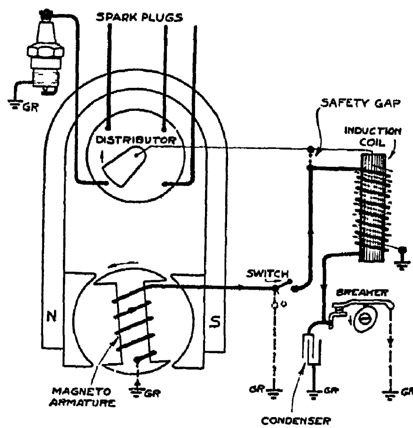


FIG 208.—Simplified wiring diagram of low-tension magneto ignition system with interrupted-primary circuit.

Assuming the breaker contacts to be closed, the low-tension current generated in the armature winding flows through the switch and the primary winding of the coil and through the breaker (on the armature shaft) to the

ground and back into the armature winding. During the next half revolution of the armature, the current in the circuit is in the reverse direction. At the desired time for the spark, which must be during the period of maximum current flow, the primary circuit is broken by the breaker. This is caused by the high point of the cam raising the contact arm from its contact with the fixed contact point. A condenser placed in parallel with the breaker points absorbs the induced current in the primary winding, caused by this sudden interruption of the current flow, and assists in rapidly breaking down the magnetism of the coil core in the same manner as in a battery ignition system. By this action, a high-tension current is induced in the fine secondary winding of the coil. The distributor, which is mounted on the magneto, receives this current at its central connection and directs it to the proper plug.

The secondary winding of the coil, as shown, is entirely separate from the primary and has its own ground connection. This is not necessary, as the two coils could be connected at their lower ends and the secondary ground be made through the armature circuit to the grounded end of that winding. The connection to the distributor would then be made from the other end of the secondary winding.

Instead of having the switch in series with the armature, and the circuit through the coil and the interrupter, so that opening the switch breaks the circuit, the switch connection might be from the insulated side of the circuit to the ground, as shown dotted. In this case the circuit would be through the coil and the interrupter when the switch was "On" When the switch was "Off," the current would have a permanent and easy path to the ground and back into the armature, so that practically no current would flow through the coil and the interrupter. In this case, grounding the switch would ground the primary current so that the coil would become inoperative and ignition would cease.

The interrupter cam has two lobes corresponding to the two current waves produced per revolution in the shuttle type of armature. (The same applies in some magnetos of the inductor type.) This arrangement is used when the number of cylinders is such that each current wave can be used for the production of a spark and is common practice for four- and six-cylinder engines.

142. Principles of the Low-tension Magneto—Interrupted-shunt Type.—A simplified circuit diagram of a low-tension magneto ignition system in which the transformer coil and breaker are in parallel, known as the *interrupted-shunt* type, is shown in Fig. 209. This is the type of system most commonly used when the low-tension magneto is employed.

From the diagram it will be seen that the primary current has two possible paths upon leaving the armature. It may go either through the interrupter, if that is closed, or through the primary winding of the coil. The

current naturally takes the easier path through the interrupter, when that is closed. In this case, there is practically no current through the coil on account of its higher resistance

When the magneto armature reaches the desired position for the spark, which is at some point during the period of maximum current flow, the interrupter is opened. This sudden interruption of the current through the shunt circuit, combined with the action of the condenser, produces an induced current in the armature circuit, and this, having no other path, rushes instantly through the primary winding of the coil This sudden current through the primary winding induces, in the secondary winding, a powerful momentary voltage which is used for the production of the spark at the plugs.

It will be noted that the spark from this type of magneto is produced on the building up of the magnetic field of the coil instead of on the breaking down of the field, as in the interrupted-primary-type system previously described. For this reason and also because of the resemblance of its action to that of the ordinary transformer, the coil is sometimes called a *transformer coil*

After the armature has passed the position of maximum current, the interrupter is closed and the armature again has the easy shunt path through which to build up its current, when it again rotates into the position of maximum current.

As shown in the diagram, the coil has a common ground connection for the two windings, making three terminal connections for the coil

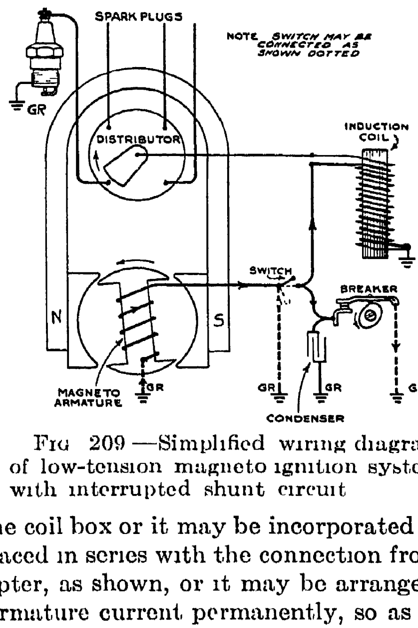


FIG 209 —Simplified wiring diagram of low-tension magneto ignition system with interrupted shunt circuit

The condenser may be placed in the coil box or it may be incorporated in the magneto The switch may be placed in series with the connection from the armature to the coil and interrupter, as shown, or it may be arranged, as shown dotted, to "ground" the armature current permanently, so as to short-circuit the current from the coil and interrupter, thus rendering them inoperative. In this latter connection, closing the switch cuts off the ignition current, while opening the switch permits the ignition to operate. A safety gap is also usually provided, either at the coil or at the magneto.

143. Combined Low-tension Magneto and Battery Ignition.— Inasmuch as the average low-tension magneto will not deliver a current sufficiently strong for ignition at the low engine-cranking speeds, practically all the low-tension magneto manufacturers who furnished equipment for automobile purposes provided the

systems with an arrangement for using battery current for starting purposes, or at least until the magneto speed was high enough to provide ignition. Such systems are generally called *dual ignition systems*, since two sources of current, namely, *battery* and *magneto*, are available and the operator can switch to one or the other as he sees fit. It should, however, be remembered that, when a dual-type ignition system is used, ignition is provided the engine through the same distributor and set of spark plugs, regardless of whether the system is operating from the battery or the magneto.

The connections at the switch are usually so made that, when the battery is used, the breaker, which is mounted on the magneto, is in series with the battery and the induction coil. The spark is induced by the interruption of the battery current through the coil, similar to the operation of the typical battery ignition system of the closed-circuit type, the system making use of the magneto breaker for interrupting the primary current and the distributor for directing the secondary current to the various spark plugs in their proper order of firing. By simply throwing the switch to the magneto-operating position the battery is disconnected and the current is furnished by the magneto armature.

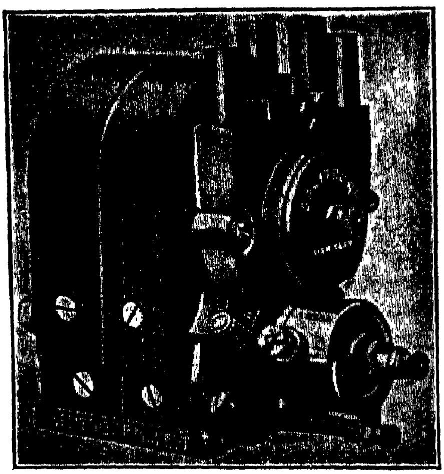


Fig. 210.—Splitdorf low-tension magneto, model T.

In some of the dual systems the switch is also provided with a push button for producing a spark in one of the engine cylinders for *starting on the spark*, as will be explained in conjunction with the different systems taken up.

144. Splitdorf Low-tension Dual Ignition System with Type T Magneto.—The Splitdorf low-tension magneto ignition system is a typical dual ignition system of the interrupted-shunt type. Figure 210 shows the Model T magneto and Fig. 211 the circuit wiring of this magneto with the typical box-type induction coil which is mounted on the dash.

A disassembled view of the magneto is shown in Fig. 196. It is of the armature-wound type having a single winding. The switch on the coil

box has three positions—"Off," "Battery," and "Magneto." Figure 211 shows the switch dotted in on the "Magneto" position. The armature current is led from the collector brush *A*, which is mounted in the breaker cap and which rubs on an insulated button on the end of the armature shaft extending through the cam, to the coil box terminal *A*, and to the lower right switch button as indicated by the arrows. From there the current has two paths back to the magneto ground. One path is by the way of terminal No. 2 over the breaker points which are normally closed; the other through the primary winding of the coil to the grounded No. 3 magneto terminal. With the contacts closed, practically all the primary current will flow across the breaker points, since the resistance is much less than that through the primary coil winding. When the points open,

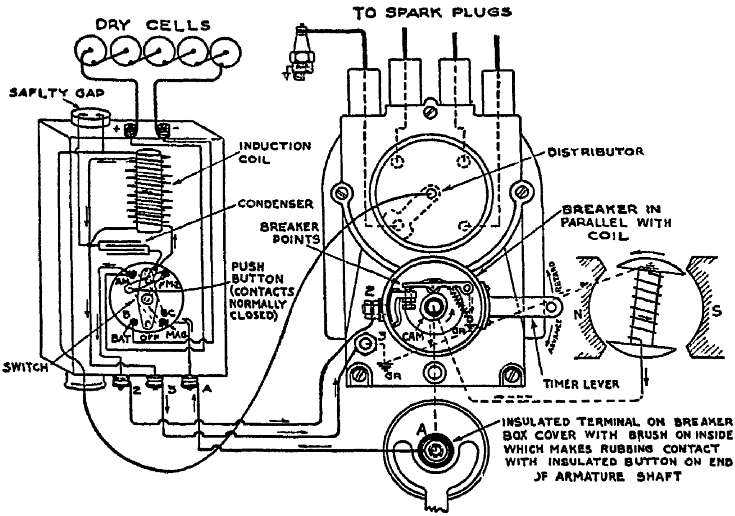


FIG 211 -Wiring diagram of Splitdorf low-tension dual ignition system.

this path is broken and there will be a sudden rush of current through the primary winding of the coil. The action of the primary current combined with the discharge from the condenser induces a high-tension current in the secondary winding of the coil. This high-tension current is directed to the proper plug by the distributor on the magneto. A safety gap is provided on the top of the coil box.

With the switch on the battery position the magneto is disconnected and the dry cells are connected to the primary circuits. When the system is operating on the battery, the coil and the breaker are in series and the system operates as an interrupted-primary current system. The secondary circuit will be the same as when operating on the magneto, namely, from the high-tension terminal on the coil to the distributor, to the plug, to the ground, and returning to the secondary winding over the primary wire connected to No. 3 grounded terminal.

The condenser is mounted in the coil and is connected so as to protect both the magneto interrupter points and the push-button contacts on the switch.

The Push Button.—The *push-button* contacts are in the primary circuit in series with the coil and are normally closed. When the switch is thrown to the "Battery" position and the breaker points are closed (which they normally are when the engine is at a standstill), the primary circuit will be completed and the coil will be magnetized by current from the dry cells. If the push button is pressed and the contacts opened, the primary circuit will be broken, causing a sudden demagnetizing of the coil and creating a secondary spark in the cylinder that is lined up to fire in accordance with the position of the distributor arm. If the cylinder should contain a combustible mixture, it is possible that a spark caused in this manner would ignite the mixture and create sufficient explosive pressure to kick the engine over, causing it to start without the usual cranking.

145. Remy Low-tension Dual Ignition System with Models P and No. 32 Magneto.—The Remy Models P and No. 32 magnetos

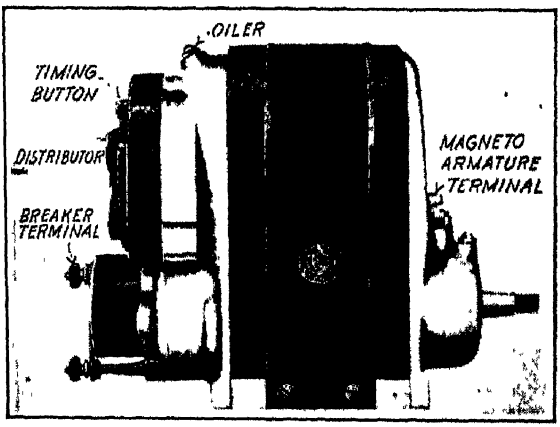


FIG. 212.—Remy magneto, models P and 32.

are similar in construction. They are of the shuttle-armature type, being designed primarily for giving a dynamic spark. They are practically the only low-tension magnetos of the armature type produced by the Remy Electric Company, the principal types of Remy magnetos being of the inductor type.

The Model P and No. 32 magneto is shown in Fig. 212. The armature is shown in Fig. 213. As may be seen, it is of the H- or shuttle-type construction with a collector ring at one end for conducting the generated low-voltage current by means of a carbon brush to the induction coil and

switch. On one end of the armature shaft is mounted the cam which actuates the breaker. The breaker is of the closed-circuit type supported on a breaker plate which can be shifted about the cam so as to advance or retard the spark. An ample timing range of 35 deg. is provided, and, because of the careful proportioning and efficiency of both magneto and coil, it is claimed that the same intensity of spark is obtained at full retard position as at full advance.

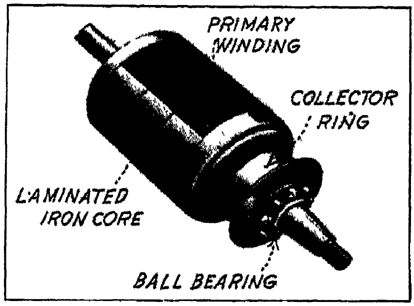


Fig 213 —Armature for Remy, model P and 32, magneto.

The breaker points are composed of platinum-iridium and should be adjusted for a maximum opening of 0.020 to 0 025 in. The entire circuit-breaker box may be readily removed, without the aid of tools, for inspection. The condenser for protecting the breaker points against sparking is mounted immediately above the armature and is sealed in a brass case, which also acts as a cover over the armature The magnets, which are two in number, are made from tungsten steel and are held in place by a sheet brass cover, which also prevents water, oil, and dust from entering the magneto.

The circuit diagram of the magneto, together with the coil, Model P (which was generally used with it), is shown in Fig. 214 As will be noticed

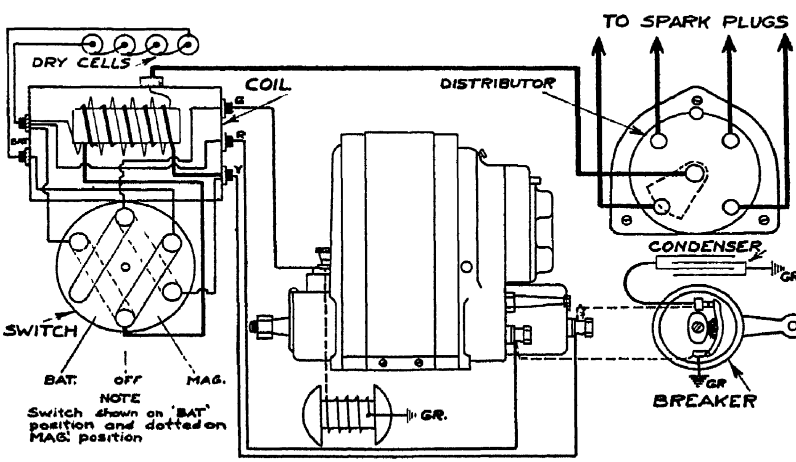


Fig. 214.—Circuit diagram for Remy, models P and 32 magneto.

from this diagram, the switch is built integral with the coil. It also forms the method of attaching it to the dash, only the switch appearing on the driver's side. The switch has three positions, "Battery," "Off," and "Magneto," and is fitted with a locking device for the prevention of unauthorized use or theft of the car.

As indicated by the letters on the coil, the three-way cable for connecting the magneto to the coil is furnished in colors, the letters *Y*, *G*, and *R* standing for yellow, green, and red respectively. The yellow wire connects to the terminal on the breaker housing, the red to the ground terminal on the magneto, and the green to the terminal on the opposite end of the magneto, which connects through a carbon brush to the armature collector ring. The two terminals on the opposite end of the coil connect to five dry cells which are used for starting purposes. A 6-volt storage battery may also be used as a substitute for the five dry cells.

In tracing the circuits in Fig. 214, it will be noted that on the "Battery" position the battery current flows from the positive side of the dry cells to the upper battery terminal on the coil, directly to terminal *R* on the opposite end of the coil to the magneto ground, thence through the breaker back to terminal *Y*, through the primary winding of the coil, returning through the switch blade to the negative side of the battery. Thus, on the "Battery" position the system operates on the interrupted-primary principle.

With the switch on the magneto position, making connections as shown by the dotted lines, the interrupted-shunt principle is employed. Assuming that the magneto current leaves by way of the collector ring over the green wire to terminal *G* on the coil, it leads through the switch to terminal *Y*, at which point the circuit divides, one path being through the breaker to the ground (when closed), the other being through the primary winding and other switch blade to the ground by way of terminal *R* Thus both circuits are completed through the ground to the grounded side of the magneto winding.

The condenser is connected across the breaker points, one side leading to the insulated contact by a flexible lead, the other to the ground. Thus, the principle of operation is quite similar to that of the Splitdorf Model T magneto.

Timing Magneto to Engine.—This magneto has a timing button incorporated in the distributor for timing the magneto to the engine. For timing the magneto, turn the engine over by crank until No. 1 piston reaches top center on the compression stroke. Press the timing button at the top of the distributor and turn the magneto shaft until the plunger of the timing button is felt to drop into the recess on the distributor gear. With the magneto in this position, couple it to the engine. It is usually unnecessary to pay attention to the position of the breaker when timing in this manner, as the breaker is automatically brought into the correct position and the distributor segment is in contact with terminal for No. 1 cylinder with this setting. It is assumed, however, that the internal timing has not been changed.

Direction of Rotation.—The location of No. 1 terminal on the distributor is determined by the direction of rotation of the magneto. When the magneto is driven clockwise, the terminal for No. 1 cylinder is located on the lower left-hand corner of the distributor head. When driven counterclockwise, the terminal for No. 1 cylinder is located on the lower right-hand corner of the distributor.

Note—These magnetos are not reversible and are intended to run in one direction only.

146. The Remy Model RL Magneto Ignition System.—The Remy magneto, Model RL, as shown in Fig. 195, is a typical low-tension magneto of the inductor type. It was used very extensively on 1913 and 1914 automobiles and trucks. A disassembled view of the magneto is shown in Fig. 197. Figure 215 shows the inductor and coil. The two wing-shaped inductors

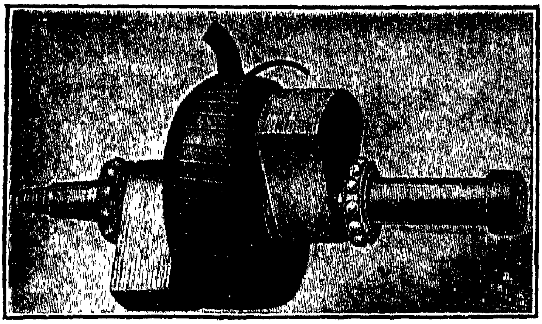


FIG 215.—Remy inductor and coil.

are mounted on a steel shaft and are revolved on either side of the stationary coil.

The path of magnetism during one complete revolution of the inductor was shown in Fig. 206. When the inductors are in the horizontal position, the flux enters one inductor, makes a right-angled turn, passes along the shaft and through the coil to the

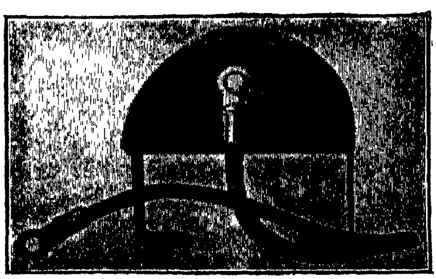


FIG. 216.— Condensor for Remy model RL magneto.

other inductor and to the other pole piece. In this position the same condition exists as when an armature of the shuttle type is in the horizontal position. When the inductors are revolved to the vertical position, Figs. 206*B* and *D*, the flux passes from one pole piece directly across and through the inductors to the other

pole piece. There is no flux through the coil. This change, therefore, produces a voltage in the coil winding. The outer ends of the inductors are of such length that when they are in the vertical position they offer a direct path from one pole piece to the other, but when they are horizontal the flux must enter the one inductor, pass through the center of the coil, and pass out through the other inductor.

This magneto will produce two current waves per revolution in the same manner as the shuttle type. The current produced is also an alternating current, since the direction of the flux through the coil is reversed each 180 deg. of revolution of the

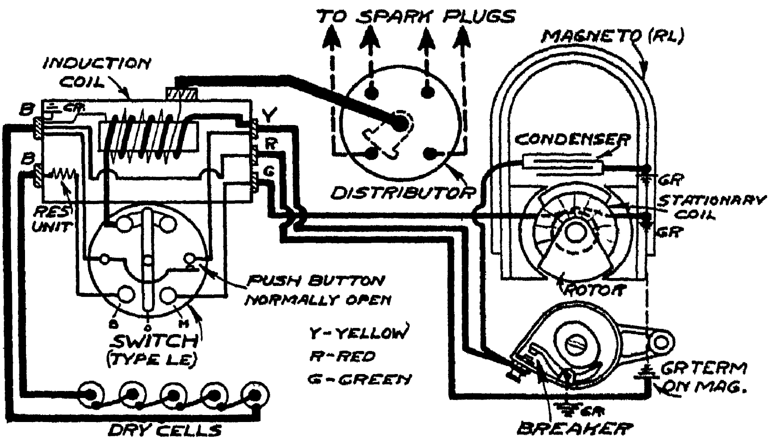


FIG. 217.—Circuit diagram of Remy low-tension magneto ignition system, model RL.

shaft. Because of the design of the parts, the current wave has an abrupt rise and fall with an almost flat top, making possible a fairly large timing range (35 deg.) with practically the same intensity of spark.

This magneto is used for jump-spark ignition, the low-tension current being generated in the coil. The secondary current from the transformer is led to the distributor on the magneto and is distributed to the different plugs of the engine. The circuit breaker, Fig. 207, is mounted on the magneto and is operated by a cam on the end of the armature shaft, the cam being mounted so as to break the circuit in proper relation to the position of the armature for maximum current. The condenser, Fig. 216, is

mounted in the arch of the magnets and is connected directly across the breaker points.

Figure 217 shows a complete wiring diagram of the Model RL magneto with type LE switch and coil. The lettering *R*, *Y*, and *G* on the coil indicates the color of the wire intended by the manufacturer to be connected to that terminal. The wiring from the coil to the magneto is connected as follows:

Red (*R*) wire goes to the ground binding post on the breaker end bracket.

Yellow (*Y*) wire goes to the contact screw post on the circuit breaker.

Green (*G*) wire goes to the insulated screw post on the breaker end bracket.

Timing.—For timing this magneto the engine should be turned over with the crank until No. 1 piston reaches top dead center on the compression stroke. The timing button at the top of the distributor should be pressed in and the magneto shaft turned until the plunger of the timing button is felt to drop into the recess on the distributor gear With the magneto in this position, it should be coupled to the engine. No attention should be paid to the breaker contacts when coupling or setting gears, as the breaker is automatically brought into the correct position, and the distributor segment is in contact with No. 1 terminal. This No. 1 terminal is plainly marked on the distributor.

147. The Ford Low-tension Magneto Ignition System.—The Ford ignition system is the only low-tension magneto ignition system being marketed at the present time for use on trucks and automobiles. A circuit diagram showing the complete system is given in Fig. 99. The principal parts of the ignition system are the *magneto*, which is built in the flywheel, the *four vibrating coils*, which are mounted in a box on the dash, and a *timer*, which operates on the front end of the camshaft.

The Ford Magneto.—The magneto consists of two principal parts, namely, the magnets which are attached to and revolve with the flywheel, and the coil plate, which is stationary, being bolted to the rear end of the crankcase

The magnets, which are 16 in number, are of the V-shape, mounted as shown in Fig. 218. They are of tungsten steel, ¾ in. wide, and should, when fully magnetized, lift from 5 to 6 lb. when tested on the pole faces. They are arranged on the flywheel with all the north poles together and all the south poles together, making a total of eight pairs of north poles and eight pairs of south poles. The pole ends are supported by brass screws to avoid magnetic leakage through the cast-iron flywheel. The center of each magnet is held in place by steel machine screws, the heads of which have a wire running through them to prevent their working loose.

The coil plate, Fig. 218, consists of a cast-iron casting having 16 lugs or cores which carry the coil winding, each coil being made up of approximately 36 turns of insulated copper ribbon. The coils, 16 in number, are all con-

nected in series so that the total voltage of the magneto is 16 times that produced by each coil.

A circuit diagram showing the scheme of the magneto is given in Fig. 219. The magnet poles pass in front of the ends of the coil cores at an air gap of

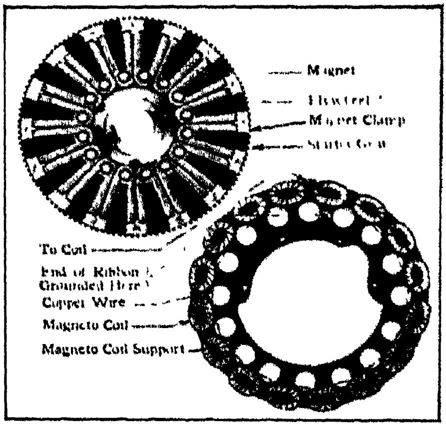


FIG 218.—The Ford magneto. The flywheel with magnets revolves while magneto coils remain stationary.

approximately $\frac{1}{32}$ in. Considering the magnetic circuit of only one magnet, when the north pole of the magnet is opposite to the core of one of the coils, the magnetic flux will pass from the north pole through the core of the

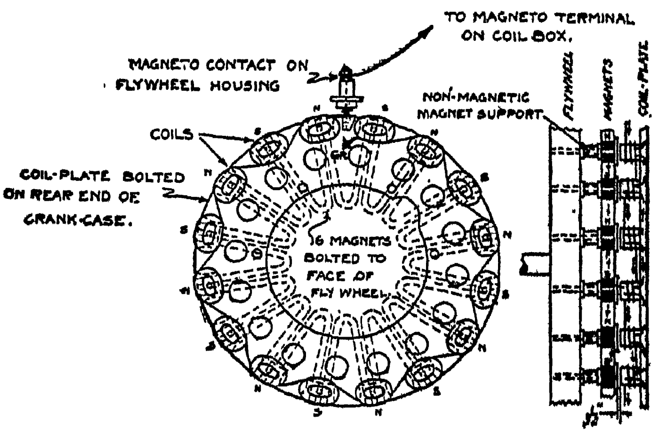


FIG. 219.—Diagram showing scheme of Ford magneto.

coil, through the coil plate casting, out through the cores of the adjacent coils to the south pole of the magnet. Similar circuits will be produced by all of the 16 magnets. Thus, the direction of magnetic flux through adjacent coils will be in opposite directions and will reverse completely through each coil,

with one-sixteenth rotation of the flywheel. Thus, there will be 16 reversals of the magnetism during one revolution.

The reversal of the magnetism through the coils, causing the lines of force to cross and recross the winding, generates an alternating current, which will also reverse 16 times or pass through eight complete cycles during each revolution of the flywheel. The current generated is conducted to the coil box on the dash by an insulated terminal connecting to one end of the winding at the top of the flywheel housing. The other end of the winding is grounded to the coil plate.

The Vibrating Coils and Coil Box.—The vibrating coil used in the Ford system was shown in Fig. 95. It has three terminals, two primary and one secondary, which, when the coil is in position, make contact with similar contacts in the coil box, the connections being as shown in Fig. 99. (The operation of the vibrating coil is described in Art. 77). The four coils are all connected at their bottom terminals by a plate which runs the full length of the coil box, the primary current from the magneto being directed through the various coils by the timer.

The Timer.—The timer, which was shown in Fig. 100, rotates in an anti-clockwise direction, when viewed from the front end of the engine. Its four terminals are wired to the low-tension terminals on the coil box, as shown in Fig. 99, in accordance with the firing order of the engine, which is 1-2-4-3. The timer generally used is of the roller-contact type; however, the brush-contact type has also been furnished as standard equipment.

148. Characteristics of the Ford Ignition System.—As may be concluded from the foregoing, the Ford magneto may be classed as a high-frequency alternating-current magneto of the inductor type. It serves merely as a source of primary current for the vibrating-coil system, operating in conjunction with a timer. Therefore, there is no need of timing the magneto itself with the engine. As in other types of magnetos, the voltage and current which it produces will be proportional to the speed of rotation.

The characteristics of the magneto as to voltage and current output are given in the following table:

R.p.m.	Miles per hour		Volts	Amperes	Cycles per sec.
	Car	Truck			
200	5	2.63	5.0	6.1	26.4
400	10	5.26	9.8	7.9	52.8
600	15	7.89	14.4	8.5	80.0
800	20	10.52	18.8	8.8	106.4
1,000	25	13.15	22.8	8.9	146.4
1,200	30	15.8	26.2	9.0	160.0

The voltage varies almost directly as the engine and car speed, being about $2\frac{1}{2}$ volts per 100 revolutions of the engine. In the Ford passenger car the voltage amounts to approximately 1 volt per mile of speed, or 5 volts at 5 miles, 9.8 volts at 10 miles, etc., as may be seen from the table. In the truck the voltage runs approximately 2 volts per mile of speed, due to the different gear ratio.

Operating, as the system does, through vibrating coils on alternating current, which varies in magnitude and frequency with changing of engine speed, interesting conditions arise. The vibrator of each coil is normally set to operate at a speed usually between 200 to 300 vibrations per second, and it will usually maintain a constant speed when operating on the battery. But the magneto voltage rises and falls rapidly, and at the same time the number of current waves per second will change with the speed. Thus,

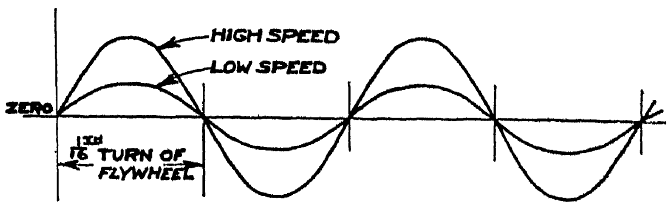


FIG 220 —Current impulses from Ford magneto during one-fourth revolution of crank shaft.

there is a tendency for the pulsations to interfere with the natural vibrating speed of the vibrator.

Since there are 16 pulses of current generated by the magneto per revolution, there will be available the 16 pulses of current for operating the vibrating coils. It should also be remembered that the engine is a four-cycle type, and therefore requires two ignition sparks for 16 pulses of current available. Furthermore, the timer rotates at one-half crankshaft speed, so that two contacts will be made during each revolution of the engine. The timer directs the current through the different coils in their proper order.

Upon examining the Ford timer, Fig. 100, it will be noticed that the metallic sectors are approximately the length of the distance between them. That is, the length of the contact equals the length of open circuit. The timer is, therefore, in contact during approximately 90 deg. of engine travel (the timer rotates at one-half crankshaft speed), after which there will be 90 deg. of off contact. Thus, while the timer is making contact, the magneto will deliver four pulses of current, the current impulses being as represented in Fig. 220. These four waves of current are available for operating the vibrator during each period, regardless of engine speed. The magnitude of each impulse, however, will vary with the engine speed, being low at low speed and high at high speed.

If the vibrating coil is connected in the circuit by the timer at the moment the current is beginning to rise from zero, or at a time the current is falling rapidly, the vibrator will have to wait until there is enough voltage and current generated to pull the vibrator off contact, thus delaying ignition. At low speed the vibrator will wait longer than at high speed, and, since it is difficult to have all the four coils adjusted to the same vibrator tension, inaccurate timing will result in the different cylinders. This means that in some cylinders there may be a lag of several degrees before the spark occurs, giving the engine a galloping action.

At high speeds, the time which is required by the vibrator to get into action after the contact is made by the timer may be so long that, before the vibrator is pulled off from its contact, the current will have reduced to zero and reversed, thus giving a very small current through the primary at the time of vibrator opening. This makes high-speed operation very difficult, due to inaccuracy of firing, and at times misfiring may result.

There will be certain speeds at which the vibrators will work very nicely, but, unfortunately, each vibrator, because of its different tune, will have a particular speed at which it will work best, while at the others it may not work so well. Sometimes misfiring will actually result at a certain spark-advance position because the vibrator opens the circuit at the instant the current is passing through zero. A slight shifting of the spark-control lever, either advance or retard, will usually eliminate this fault.

Thus, the operator of the car must find the best running position of the spark lever by trial after the engine is started, and must constantly vary the spark to advance and retard to obtain the best operation of the engine. At best, the engine cannot possibly fire as accurately as it would if equipped with a good single-spark type of system, such as a high-tension magneto or a battery-type ignition system.

149. Timing the Ford Ignition System.—In the Ford ignition system, ignition occurs at the time the timer makes contact, due to the interrupting of the circuit by the vibrator, as previously explained. The time of spark is, therefore, set according to the *making* of the timer contact instead of at the time the contacts open, as is the case in a single-spark battery-type system.

As a rule, the roller in the timer is set so that it will be just ready to make contact with timer segment for No. 1 cylinder when the piston in that cylinder is on top dead-center position at the end of the compression stroke, or slightly past, and the spark-control lever on the steering column fully retarded. This setting is obtained when, with the switch on the "Battery" position, No. 1 coil vibrates the instant the spark-control lever is moved in the advance direction.

SECTION IX

HIGH-TENSION MAGNETOS—ARMATURE TYPES

150. High-tension Magnetos.—In the previous section, Sec. VIII, magnetos which generated low-voltage current only were discussed. These were included for the primary reason that the high-tension magneto, which is used on practically all trucks, tractors, and some 10 to 15 per cent of the passenger automobiles, is constructed and operates on the same general principles that are involved in the low-tension types.

Under the name of high-tension magneto should be included all magnetos which generate directly in the magneto winding a current of sufficiently high voltage for jump-spark ignition without the aid of a separate induction coil. As a matter of fact, the magneto winding, if of the armature type, or the coil, if of the inductor type, contains both a primary and secondary winding similar to the winding of a non-vibrating-type induction coil instead of the usual single winding found in the low-tension magneto. The true high-tension magneto must not be confused with the so-called high-tension magneto in which the armature current is transformed by a coil in the top of the magneto, instead of outside, as is done in the low-tension type. The coil is sometimes contained in the magneto assembly merely for convenience, usually in the arch of the magnets, but this does not make it a high-tension magneto in the correct sense of the term.

Incorporated in the high-tension magneto are to be found the interrupter, the distributor and the condenser, so that the magneto contains within itself practically all the essentials of a complete ignition system, the only necessary outside parts being the spark plugs with necessary wiring from the distributor, and a switch for controlling the ignition. The high-tension magneto is built in both the armature-wound and inductor types, as is the low-tension magneto.

151. Construction of Typical High-tension Armature-type Magneto—Bosch Model DU4.—A typical example of the high-

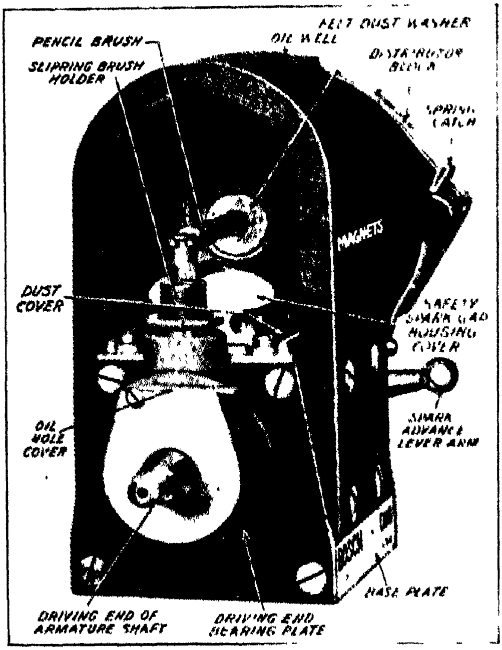


FIG. 221.—Drive-end view of Bosch magneto, model DU1.

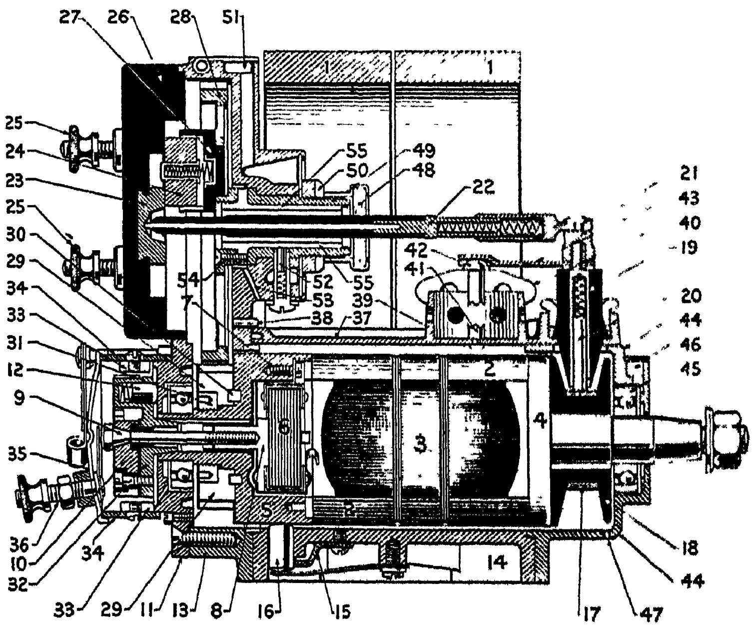


FIG. 222.—Sectional view of Bosch magneto, model DU4, showing construction.

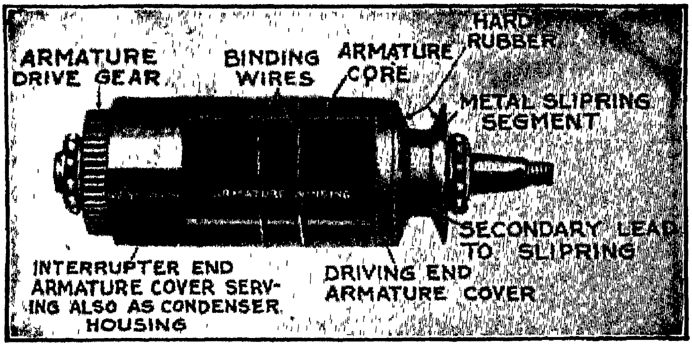


Fig. 223.—Armature for Bosch DU4 high-tension magneto.

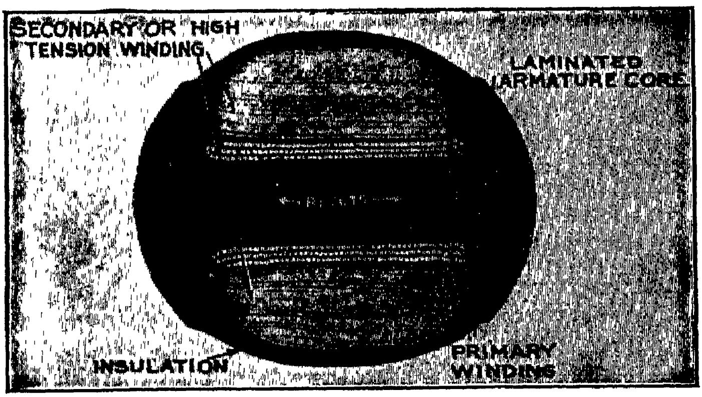


Fig. 224.—Cross-sectional view of Bosch high-tension magneto armature.

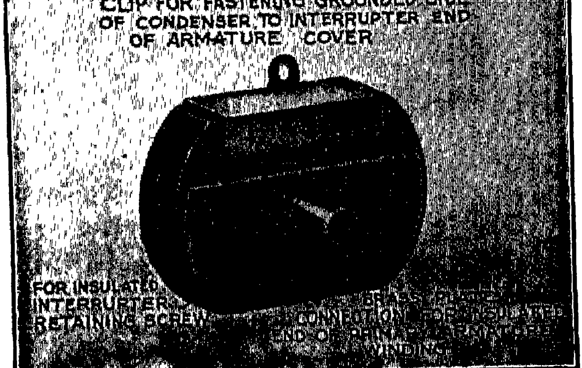


Fig. 225.—Condenser of Bosch DU4 high-tension magneto.

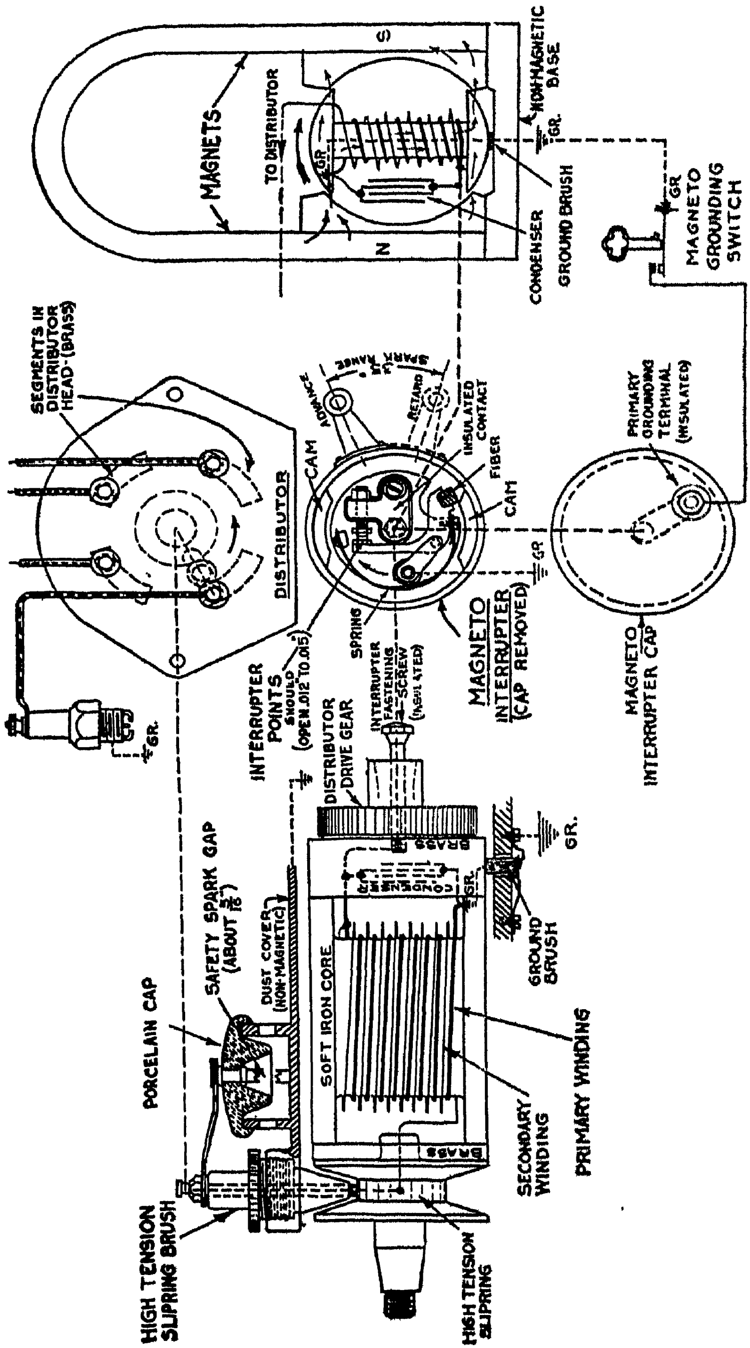


FIG. 226.—Circuit diagram of Bosch DU4 high-tension magneto.

tension magneto, armature type, is shown in Fig. 221, which shows the driving end of the Bosch Model DU4. The general construction of this magneto is shown in Fig. 222. As will be noted, the armature or rotating element, Fig. 223, is mounted on ball

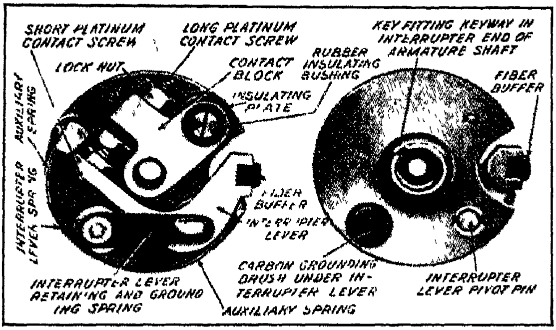


FIG. 227.—Circuit breaker for Bosch DU4 magneto. (Left) front view, (right) back view.

bearings, which are supported in the end housing, the armature core rotating between the magnet pole pieces. A cross-sectional view of the armature is shown in Fig. 224. This armature consists of a soft-iron core, a primary winding of comparatively few

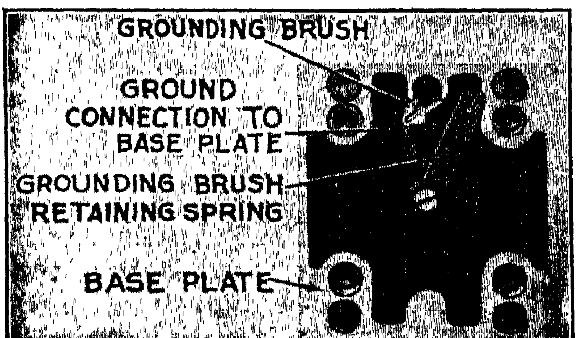


FIG. 228.—Bottom view of magneto base plate showing ground brush.

turns of coarse wire, a secondary winding of many turns of fine wire wound on the outside of the primary, and a condenser.

The condenser, Fig. 225, is mounted in the end of the armature housing and, as may be seen in Fig. 226, is connected so as to protect the contact points. The interrupter or circuit breaker,

as shown in Fig. 227, is mounted on one end of the armature shaft and revolves with it. The cams for actuating the interrupter arm are on the inside of the interrupter housing, as shown in Fig. 226. This arrangement is the reverse of that of the usual low-tension magneto, which usually has the cam on the armature shaft and the interrupter mounted in the housing. By having the interrupter, the condenser, and the primary winding all on the armature, the entire primary circuit is thus contained in the armature, forming a very compact and efficient unit.

As will be noted in Fig. 226, which shows the complete circuit diagram of the magneto, one end of the primary winding is grounded on the core, and the live end brought out to the insulated side of the interrupter device. The grounded end of the secondary winding is connected to the live end of the primary winding, thus making one winding a continuation of the other The magneto armature core is grounded to the base by the ground brush shown in Fig. 228.

152. The Magneto Interrupter.—As shown in Fig. 227, the magneto interrupter mechanism is mounted on a circular disc which is held rigid to the armature shaft by the interrupter fastening screw shown in Fig. 226. The relative position of the interrupter to the armature is fixed by a keyway in the end of the armature shaft which is bored taper. The fastening screw, Fig. 226, also forms the electrical connection between the stationary (insulated) half of the interrupter and the primary winding of the armature. This fastening screw also makes connection with the insulated terminal of the condenser, the other terminal of which is grounded, as are also one end of the primary winding and the movable contact arm of the interrupter.

Twice during each revolution of the armature the primary circuit closes and opens, this action being caused by the fiber block on the interrupter lever striking the two steel cams on the inside of the interrupter housing. When the interrupter is not being acted upon by the cams, the interrupter points are normally held closed by spring tension; consequently, the primary circuit is also closed. It is important in this type of interrupter that the interrupter lever unit be accurately balanced on its pivot to insure proper opening and closing of the points at high rotating speed and that the spring does not drag on the inside of the breaker

housing. The interrupter points are made of platinum and should be adjusted to open 0.012 to 0.015 in. on engines of normal compression.

153. Principles of Operation of Bosch DU4 High-tension Magneto.—The function of the interrupter or breaker, is to interrupt the circuit of the primary winding of the armature when a high-tension spark is to occur at the plug, the action in the armature being similar to that of an induction coil. This interruption must take place when the flow of current through the primary winding is at, or near, its maximum value. This occurs twice per revolution when the armature core is approximately in a vertical position, as shown at the right in Fig. 226, the same as in the low-tension magneto. In this position, the corner of the armature is just leaving the corner of the pole piece and the winding is cutting the maximum number of magnetic lines of force.

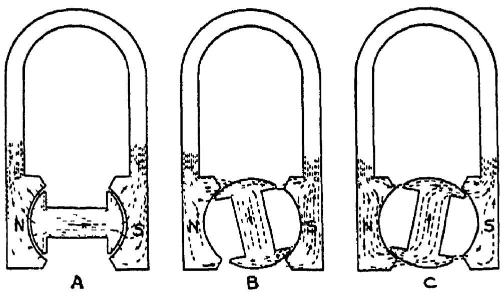


FIG. 229.—Distribution of magnetic flux through magneto armature core for various positions—rotation clockwise

Theory of Operation.—Figures 229*A*, *B*, and *C* show the distribution of the magnetic flux through the armature core for various armature positions. Because of the rotation of both the primary and the secondary windings of the armature, and the consequent cutting of the magnetic lines of force by both windings, a voltage proportional to the number of turns in the two windings is generated in both the primary and secondary circuits.

A simplified diagram of the usual armature-type high-tension magneto is shown in Fig. 230. By comparing this figure with Fig. 229, it is evident that during the period of rotation, when the magnetic field is passing through the armature core, the interrupter points are closed, thus completing (by short-circuiting) the circuit through the primary winding. The current thus generated in the primary winding will flow around the core, causing the core to become magnetized in a cross-direction, as shown in Fig. 230. At approximately the instant when the generated voltage is

greatest, the interrupter breaks the primary circuit, permitting the armature core to demagnetize instantly. This causes a high voltage to be induced in the secondary winding in the same direction as the generated voltage. The induced current produced by the interruption of the primary circuit lasts only a short time and, if acting alone, would produce but a single flash of short duration at the spark plug. On account of the revolving of the secondary winding in the magnetic field, however, a more continuous current of lower voltage is generated. This generated voltage alone is not sufficient to break down the resistance of the gap in the spark plug, but, at the instant the primary circuit is interrupted, the induced voltage, due to the collapsing field, is sufficient to break down this resistance. The somewhat lower voltage of the generated current is then able to maintain the flow of current across the gap, thus producing not an instantaneous flash, but a hot flame which lasts for a considerable period of armature rotation. The

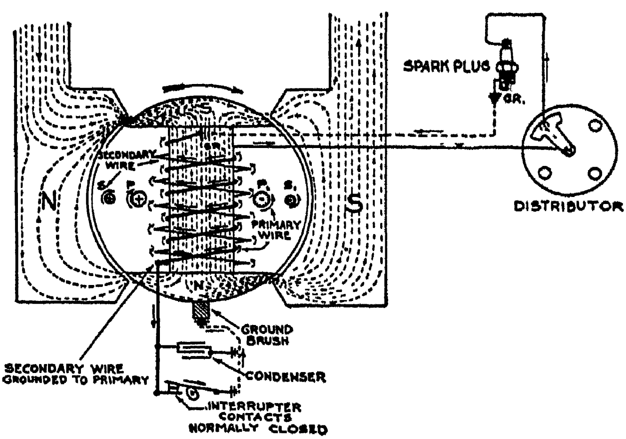


FIG. 230.—Simplified diagram of typical armature type high-tension magneto showing cross-magnetization of armature due to current generated in the primary and secondary windings at the time of contact opening.

heat produced by this prolonged spark is much more intense than that produced by the short flash caused by the induced current.

In Bosch magnetos, having a variable spark advance, the interrupter points are timed to open when the corner of the armature has left the corner of the pole piece about 1/16 in., with the interrupter housing shifted to full advance position. The timing lever may be advanced about 35 deg.; consequently, when the interrupter housing is fully retarded, the armature has passed the pole piece about 3/8 in. when the contacts open. Thus, the best spark is obtained with the interrupter in full advance position, which is the normal operating position at high engine speeds.

154. Importance of Armature High-tension Insulation.—The high-tension winding, being wound on the outside of the low-

tension winding (which is wound first on the core), must be very carefully insulated to prevent puncturing of this insulation by the high voltage while the magneto is operating.

It is evident from Fig. 230 that the armature is in a vertical position at the time sparks are being developed for ignition. Thus, the high-tension winding is close to the field pole pieces, which are, of course, grounded to the beginning of the high-tension winding. Therefore, there is a great tendency for sparks to jump from the high-tension winding to the pole piece, thus injuring the insulation. It is then plain that, if any part of this insulated surface or covering of the high-tension wire is injured by a mechanical blow or by some sharp puncture, sparks will jump through it, injuring the insulation permanently.

155. The Condenser.—The condenser (Fig. 225) in most high-tension armature-type magnetos is located in one end of the armature. It is connected in parallel with the primary winding and the interrupter circuit. As previously stated, the purpose of the condenser is to absorb the induced charge in the primary winding to prevent the discharge of this current across the interrupter points when the circuit is broken. Conversely, the charge in the condenser surges back into the primary winding in the opposite direction to that of the generated primary current, thus causing a more rapid demagnetization of the armature, and producing a higher voltage in the secondary winding than would be otherwise obtained. Its function is the same as explained in connection with the induction coil.

The condenser used for high-tension magneto service is usually of the mica type, that is, the alternate layers of tin foil are separated by thin mica sheets instead of paraffin paper. These condensers must be of especially good quality, since they must be compact and are subjected to high mechanical and electrical strains. As a rule, it is not easy to replace a defective condenser, so that its injury should if possible be avoided.

156. The High-tension Magneto Distributor.—The distributor used in high-tension magneto ignition is usually of the wipe-contact type, employing carbon for making the contact, similar to that explained in connection with certain battery ignition equipment. It will be evident from Fig. 226 that one end of the high-tension winding is grounded to the live end of the primary, while the other end terminates in the collector ring or slip ring, on which slides a carbon brush insulated from the magneto

frame. The secondary current is conducted from this carbon brush to the center contact of the distributor or distributing arm from which it is directed to the various cable connections and spark plugs in the proper order of firing. After jumping the spark-plug points, the high-tension current returns through the engine frame and the ground brush in the base of the magneto to the armature core and back to the beginning of the secondary winding.

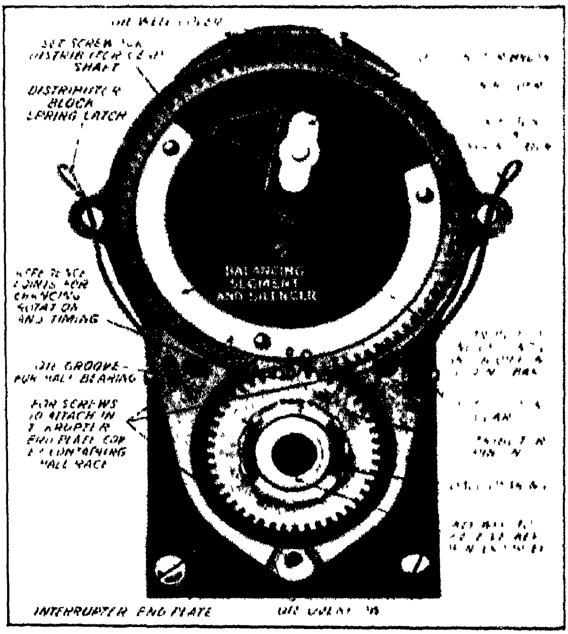


FIG. 231.—Distributor end view of Bosch magneto showing markings for timing distributor with armature.

Distributor and Armature Speeds.—As in the low-tension armature type of magneto, two sparks are produced per revolution in the high-tension type. The distributor, therefore, is similar to that found on the low-tension magneto and is driven at similar speeds. The only difference is that the secondary current is received direct from the armature instead of being brought to the distributor from a transformer coil. The distributor has as many terminals as there are engine cylinders and is, therefore, driven at one-half the speed of the crankshaft. Thus, for a four-cylinder engine the distributor has four segments and is driven at one-half armature speed and for a six-cylinder engine it has six segments and is driven at one-third armature speed—the same as in the low-tension armature-type magneto.

Since the same gear ratios are used between the armature and the distributor as in the low-tension magneto, the armature speeds with respect to the camshaft will also be similar, namely, crankshaft speed for a four-cylinder engine and one and one-half times crankshaft speed for one of the six-cylinder type. Likewise, for an eight- or a twelve-cylinder engine a magneto of this type (one giving two sparks per revolution) must be driven at twice or three times crankshaft speed, respectively, in order to produce the required number of sparks per revolution of the engine.

Timing Distributor with Armature.—Care should be taken in assembling the magneto to get the distributor gear timed correctly with the armature, so that the distributor brush will be in proper alignment with the distributor-head segment when the interrupter points open, and with the breaker housing in either the advance or the retard position. *In the full advance position, the distributor brush should be moving onto the distributor-head segment when the interrupter contacts open and should be leaving the same segment at the moment the contacts open, with the breaker housing shifted to full retard position.*

Figure 231 shows the punch markings on the distributor gears of the Bosch magneto for timing the distributor with the armature, the magneto having clockwise direction of rotation. For clockwise rotation the punch mark C on the distributor gear should match with the punch mark on the armature gear, while in a magneto with anti-clockwise rotation the gears should be matched so that the punch mark *A* will match with the punch mark on the armature

The direction of armature rotation is usually indicated by an arrow stamped on the magneto housing near the driving end of the armature shaft.

157. The Safety Spark Gap.—In order to protect the insulation of the armature and of the current-conducting parts against excessive voltage, a safety spark gap of about 5⁄16 in. is usually provided, as shown in Fig. 226. If, during magneto operation, the voltage should become excessive, say, due to a spark-plug wire becoming disconnected or the spark-plug electrodes becoming too far apart, the spark will jump this gap, thereby preventing puncturing of the insulation. The secondary current should not be permitted to jump the safety gap for any length of time, as the continued discharge of the current over the safety gap is liable to damage the magneto winding and the condenser.

158. High-tension Magneto Grounding Brushes.—As previously pointed out, the function of the grounding brush is to provide a positive ground connection between the revolving armature and the magneto frame. This grounding brush is important because the high-tension current produced in the magneto armature must get to the frame by this means, or else it will have to

pass through the lubricated bearings. This would cause carbonizing of the oil and eventual cutting of the bearing, causing serious damage to the armature—usually wrecking it due to striking the pole pieces. In the Bosch magneto the outside bearing race (the one supported in the end housing) is actually insulated by fiber to prevent current from flowing through the bearing.

In the armature-type magneto, Fig. 226, it should be remembered that the primary current does not have to pass to and from the magneto frame, because the rotating breaker has a permanent connection to the primary winding. Thus, it is only the high-tension current which passes through the magneto frame that must be guarded against. In order to be doubly sure of this point, two grounding brushes will usually be found on the better makes of magnetos, one to rub against the armature core, as indicated in Fig. 226, and another on the base of the breaker, so that it rubs against the front plate of the magneto frame. Both should make proper contact at all times.

159. The Magneto Grounding Switch.—In order to cut off the ignition without damaging the windings, the primary current must be short-circuited so that it will not be interrupted when the interrupter contact points open. This is arranged for by connecting a wire from the insulated terminal on the breaker cover to a simple ground switch, one side of which connects to the engine or chassis frame. The terminal on the breaker cover is connected by a brush to the insulated half of the interrupter, Fig. 226, so that when the switch is closed the primary current is short-circuited through the switch and ground, and the magneto ceases to generate sufficient voltage in the secondary winding to jump the spark-plug points, thus preventing ignition.

160. The Bosch High-tension Magneto, Type NU4.—The Bosch magneto, type NU4, which was introduced on many 1915 and 1916 four-cylinder cars, is shown in Fig. 232. It is of the high-tension, armature-wound type and is suitable only for four-cylinder, four-cycle engines of the automobile type. A distinct feature of this magneto is the absence of the usual gear-driven distributor, this being incorporated in the form of a double high-tension slip ring mounted on one end of the armature shaft as shown in Fig. 233. The magneto interrupter, Fig. 234, is the same as that used in the ordinary Bosch high-tension magneto.

A circuit diagram of this magneto is shown in Fig. 235. The circuit of the primary winding is the same as for the Bosch DU4

shown in Fig. 226. The secondary winding, however, is not connected to the primary, its two ends being connected to the two metal segments in the slip ring, which is mounted on the armature just inside of the driving-shaft end plate of the magneto.

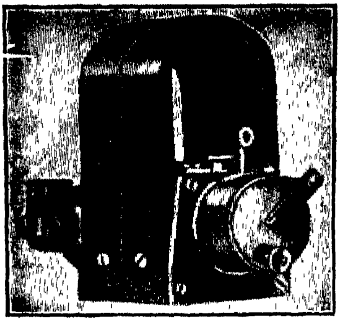


FIG. 232.—Bosch high-tension magneto, type NU4

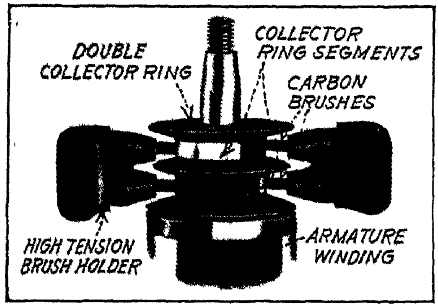


FIG. 233.—Arrangement of high-tension slip ring and brushes on Bosch type NU4 armature.

The slip ring has two grooves, each containing one of the two metal segments. These segments are set diametrically opposite on the armature shaft (180 deg. apart) and are insulated from each other as well as from the armature core and the magneto frame.

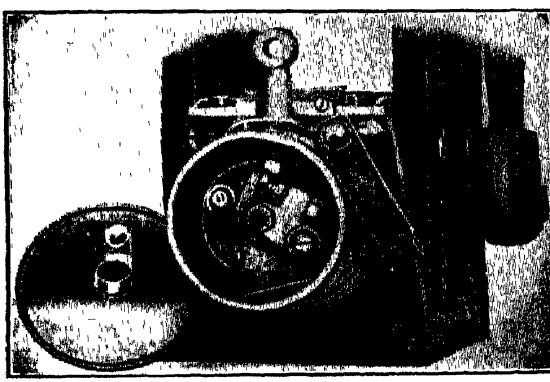


FIG. 234.—Interrupter end of Bosch "NU4" magneto.

The four slip-ring brushes which collect the secondary current are supported by two double brush holders, one on each side of the driving-shaft end plate. Each holder carries two brushes so arranged that each brush bears against the slip ring in a separate

groove. Upon rotation of the armature, the metal segment in one slip-ring groove makes contact with a brush on one side of the magneto at the same time that the metal segment in the other slip-ring groove comes into contact with a brush on the opposite side of the magneto. The marks "1" and "2" appearing in white on both brush holders indicate pairs of brushes receiving simultaneous contact, those marked "1" constituting one pair, and those marked "2," the other.

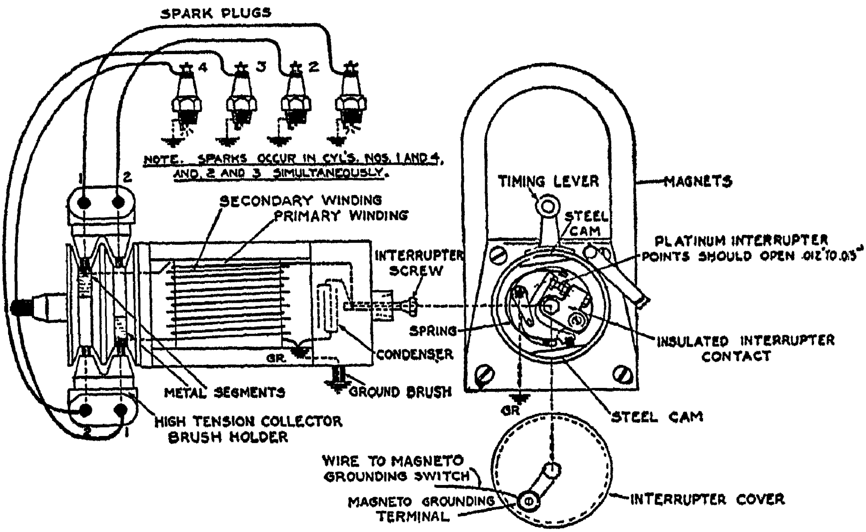


FIG. 235.—Circuit diagram of Bosch "NU4" high-tension magneto.

From the wiring diagram it is important to note that, since two of the four slip-ring brushes make contact simultaneously and each is connected by cable to the spark plug in one of the cylinders, the secondary circuit always includes two plugs, the sparks occurring in two cylinders at the same time, namely, cylinders Nos. 1 and 4 or Nos. 2 and 3. Only one of these sparks, if properly timed, will cause ignition, since in a four-cylinder engine when No. 1 cylinder is under compression ready for ignition No. 4 piston is finishing its exhaust stroke and the cylinder contains nothing but burned exhaust gases. The same relation exists when each cylinder is ready for ignition, the other cylinder in which the spark occurs containing non-combustible exhaust gases.

Caution in Timing the Bosch Magneto, Type NU4.—Care should be taken in timing this type of magneto, so that when it is fully retarded the spark will not occur in the supposedly "dead" cylinder after the intake valve has opened. This point is usually a crank angle of about 8 to 10 deg. past upper dead center. The platinum contact points should be adjusted to open 0.015 in., while the spark plugs should be adjusted to a gap of 0.020 to 0.030 in.

161. The Bosch High-tension Magneto, Type B.—The Bosch type B magneto, Fig. 236, is a recent product of the American Bosch Magneto Corporation, and is fitted to many engines made after the spring of 1920. The four-cylinder type magneto is known as the type "B4," while the six-cylinder type is known as type "B6." These are of similar construction, the principal

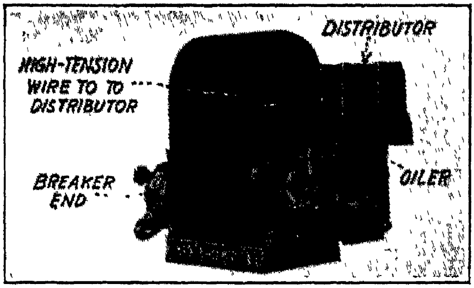


FIG. 236.—Bosch high-tension magneto, type B.

difference being in the distributor head and the gear ratio between armature and distributor shafts.

Like other high-tension magnetos manufactured by this company, the type B magneto generates high-tension current directly in the magneto armature without the aid of a step-up coil. It also has a breaker and a distributor built into the magneto. The magneto is equal electrically and

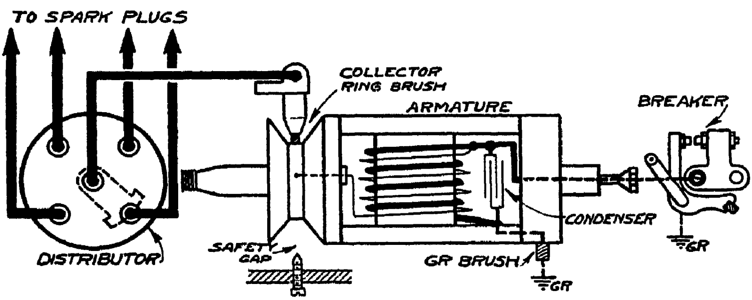


FIG. 237.—Circuit diagram of Bosch, type B4, magneto.

mechanically to any of the Bosch types which have preceded it, the principal difference being in the distributor arrangement. The distributor, instead of being mounted over the interrupter housing, is located at the drive end of the magneto, as may be seen in Fig. 236. It is mounted at the top of the vertical shaft driven by the spiral gears from the armature shaft, the gear ratio being dependent upon whether the magneto is of the four- or the six-cylinder type. In the four-cylinder type, the distributor speed will be one-

half the armature speed, while in the six-cylinder type it will be one-third the armature speed. It should be remembered that the distributor speed is always one-half crankshaft speed for four-cycle engines.

Magneto Circuits.—A circuit diagram of the Bosch magneto, type B4, is shown in Fig. 237. As may be seen from a study of this diagram, the beginning of the armature primary circuit is grounded to the armature core, while the live end is connected by an interrupter fastening screw to the insulated contact block, as in the Bosch magnetos previously described. The actions of the breaker, armature windings, and condenser are also identical. The interrupter contacts should be adjusted to open 0.015 in.

In the type B magneto the safety gap is located between a pin in the metal insert in the distributor and the sharp edge on the inner surface of the distributor housing. In a few of the first ones put out the spark gap was provided between the high-tension collector ring and a screw extending from the armature housing as shown in Fig. 237. The safety gap should be adjusted to an opening of about $\frac{5}{16}$ in.

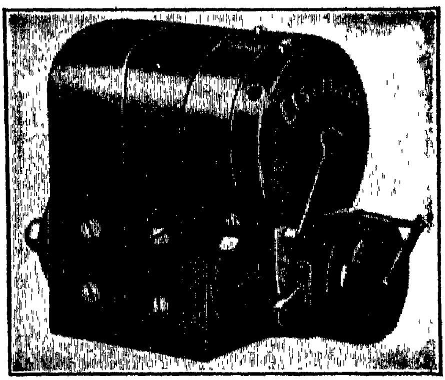


FIG. 238.—Eisemann high-tension magneto, type G4.

162. The Eisemann High-tension Magneto, Type G4.

—The Eisemann high-tension magneto, type G4, Fig. 238, is typical of the various models of the Eisemann magneto. It is made in two types known as G4-I Edition, and G4-II Edition. The principal differences between the two models are in the design of the interrupter mechanism and in the construction of the armature housing.

In the type G4-I Edition, shown in Fig. 239, the movable contact of the interrupter is carried on a flat spring instead of on the usual rocking-type lever. The interrupter points are actuated by the spring striking the two fiber cams on either side of the center part of the timing lever body. The fixed end of the spring is grounded to the magneto frame through a grounding brush which bears on the inside of the timing lever body. In

this type of magneto, the interrupter platinum points may be adjusted without removing the timer body. In the type G4-II Edition, Fig. 240, the usual form of rocking-type interrupter, Fig. 241, is used. The interrupter lever is actuated by two steel segments or cams mounted on the inside of the timing lever body, as shown in Fig. 240. The platinum contacts in both types of magnetos should be adjusted to open 0.010 to 0.014 in.

The armature housing or frame of the type G4-II Edition consists of the unit-cast construction shown in Fig. 242, whereas the I Edition housing is

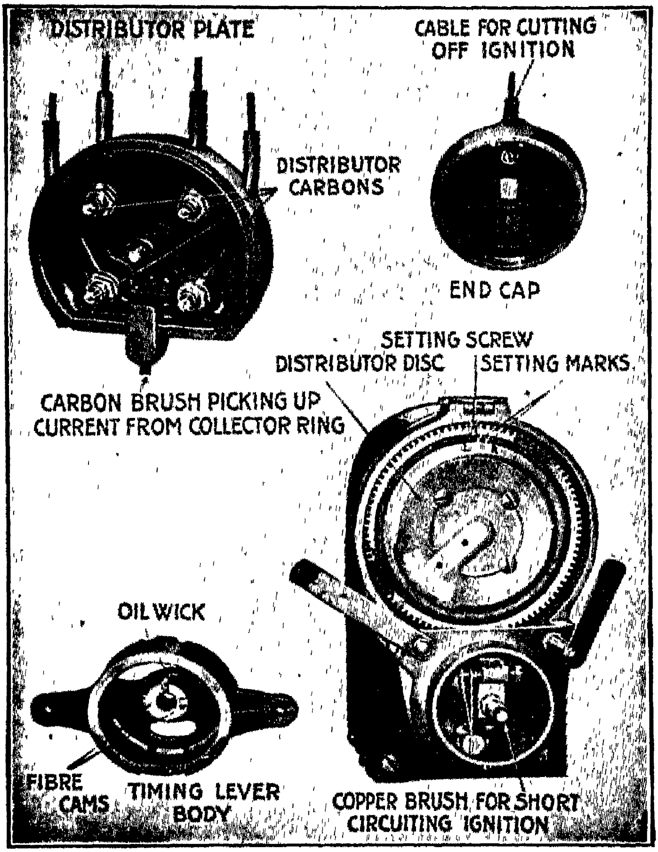


FIG. 239.—Principal parts of Eisemann high-tension magneto, type G4—I Edition.

built up of several parts screwed together. This unit casting is extremely rigid, thus eliminating all danger of loosened screws or end plates due to vibration or accidental twisting. Another advantage of the unit casting is the absence of any joints. Consequently, an absolutely water-, oil-, and dust-tight protection is provided for the vital elements, such as the winding and the condenser. The unit casting may be bored out and machined

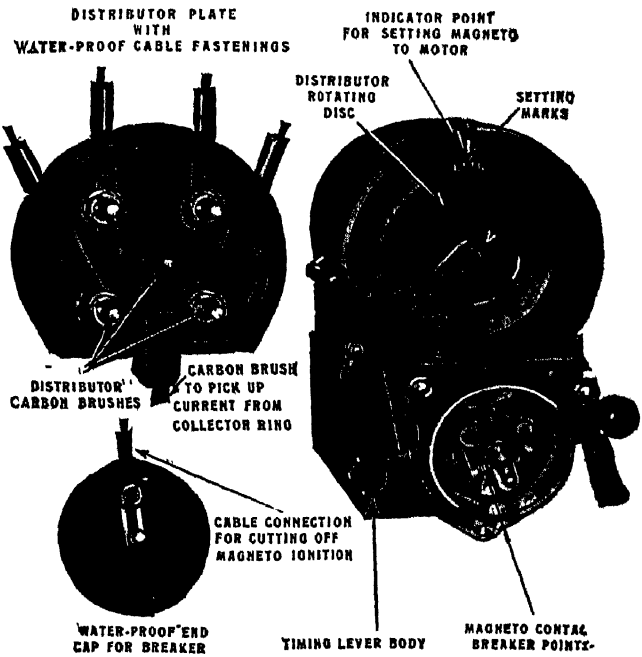


FIG. 240.—Principal parts of Eisemann high-tension magneto, type G4—II Edition.

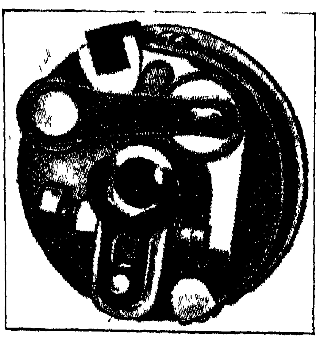


FIG. 241.—Breaker used on Eisemann magneto, type G—II Edition.

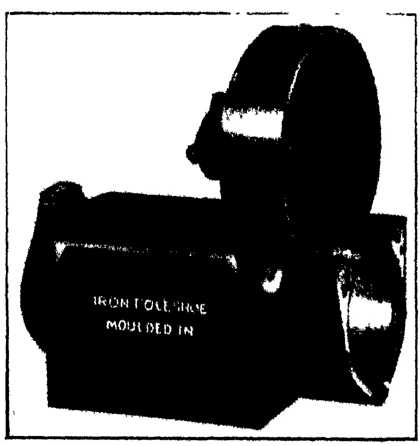


FIG. 242.—Frame casting for Eisemann magneto, type G4—II Edition.

all in one piece, and, because of its rigidity, a smaller running clearance between the armature and the poles of the magnets can be maintained. This tends to give increased magnetic efficiency and, as a result, a much hotter spark.

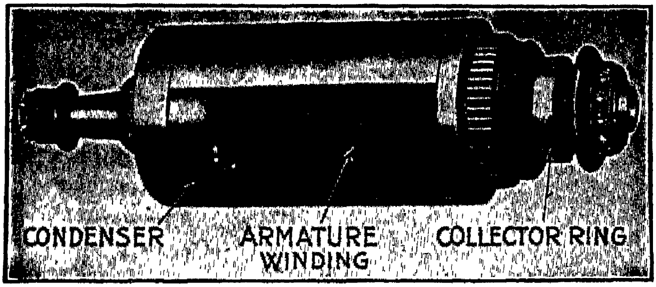


FIG. 243.—Armature for Eisemann magneto

The Armature.—The armature used in the Eisemann magneto is shown in Fig 243. The armature core carries the winding and is of the H-shaped type, similar to that shown in Fig. 224 On this core are wound a few layers of medium-sized copper wire, the beginning end of which is connected

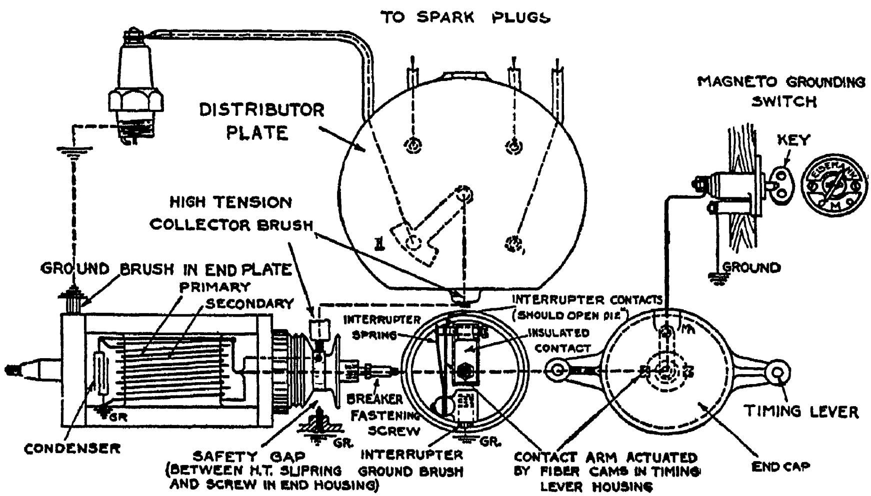


FIG. 244.—Circuit diagram of Eisemann high-tension magneto, type G4—I Edition.

through the interrupter fastening screw to the insulated contact of the breaker mechanism. Over this primary winding is wound the secondary winding consisting of many turns of very fine copper wire, the wire itself being insulated its entire length and the layers carefully insulated from each other. A circuit diagram of the Eisemann type G4—I Edition is shown

in Fig. 244. It will be noticed that the beginning of the secondary is connected directly to the end of the primary winding, and the end is led to the collector ring which is mounted on the same end of the armature as the interrupter. The condenser, which is connected so as to protect the interrupter points, is mounted in the opposite end of the armature.

The Distributor.—By placing the collector ring on the same end of the magneto as the distributor head, the necessity of carrying the high-tension current around the magneto by means of brushes and conductors is done away with. A brush in the distributor plate carried straight down to a contact with the collector ring is used and the high-tension current is carried in this manner directly to the center brush in the distributor plate. This center brush, in turn, makes contact with the metal insert of the distributor disc. As this disc is attached to the distributor gear it rotates with it, so that the metal insert makes contact in rotation with each of the outside carbons of the distributor plate from which the current is led to the spark plugs by the high-tension cables.

The Safety Spark Gap.—The safety spark gap is located in the breaker end of the magneto instead of in the arch of the magnets, as in the usual armature-wound-type magneto. It consists of a gap of about $\frac{5}{16}$ in. between the collector ring and the point of a screw placed in the armature housing immediately behind the breaker.

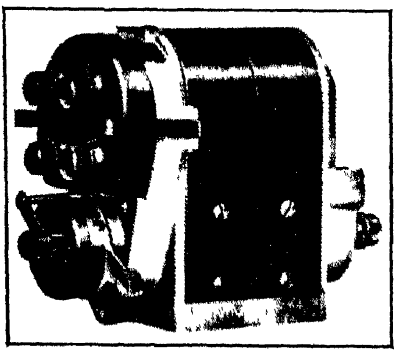


Fig. 245.—The Simms high-tension magneto.

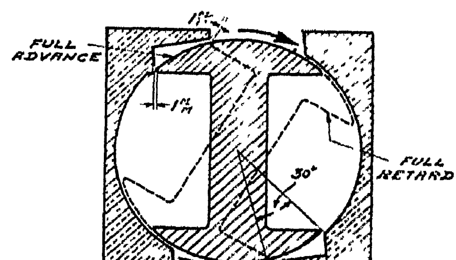


Fig. 246.—Pole construction of Simms magneto.

163. The Simms High-tension Magneto.—The Simms magneto, as shown in Fig. 245, is in many respects similar to the Eisemann and the Bosch in construction. A special feature of the Simms magneto is the design of the pole pieces, which have extensions on the trailing corners with a milled slot in the pole pieces as shown in Fig. 246.

The object of this slot is to make the magnetic circuit break twice—in effect. That is, the edge of the armature core passing the first edge of the pole pieces will cause a sudden change in flux intensity in the core of the coil,

thus generating an impulse of current. The trailing pole corner then becomes saturated with magnetism and there is very little change of flux through the armature until the armature short-circuits across between the pole tips and then breaks the magnetic circuit. Thus, two pulses of current are produced. These are spaced by the angular distance between the first edge and the trailing corner of the pole tips. In this manner the advance

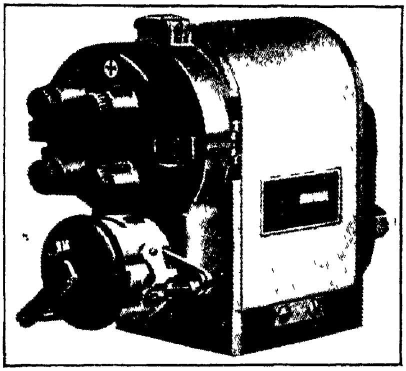


FIG. 247.—The Berling magneto.

spark is obtained when the edge of the armature leaves the inner corner of the pole piece and the retard spark when it leaves the outer or trailing corner, as shown in Fig 246. This gives a more uniform current value from advance to retard positions of the breaker and thus assists in producing a better spark when the breaker is in retard position, such as is desirable when the engine is being cranked on the magneto

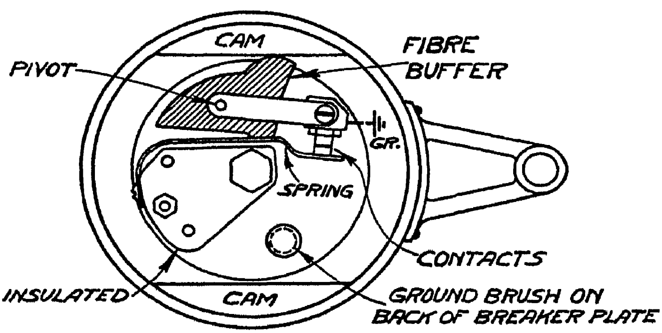


FIG. 248.—Breaker for Berling magneto.

164. The Berling High-tension Magneto.—The Berling magneto, a typical example of which is shown in Fig. 247, is also similar in general construction to the early Bosch models, such as the Bosch DU4. The principal points of difference, however, are in

the pole pieces, which are laminated in order to reduce the eddy currents, thereby increasing the magneto efficiency, particularly at high speeds. The breaker is also somewhat different in design, as may be seen in Fig. 218. The breaker contact points are made

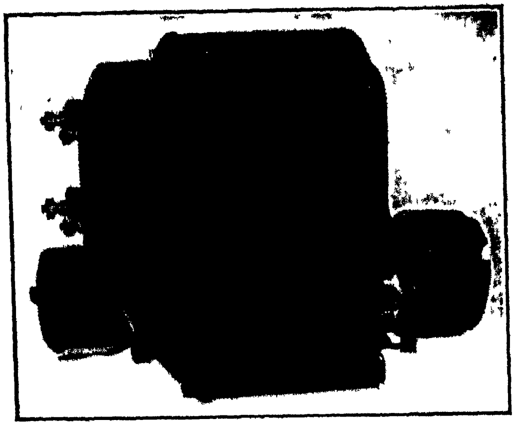


FIG. 249—Kingston high-tension magneto, model O, showing impulse starter at right.

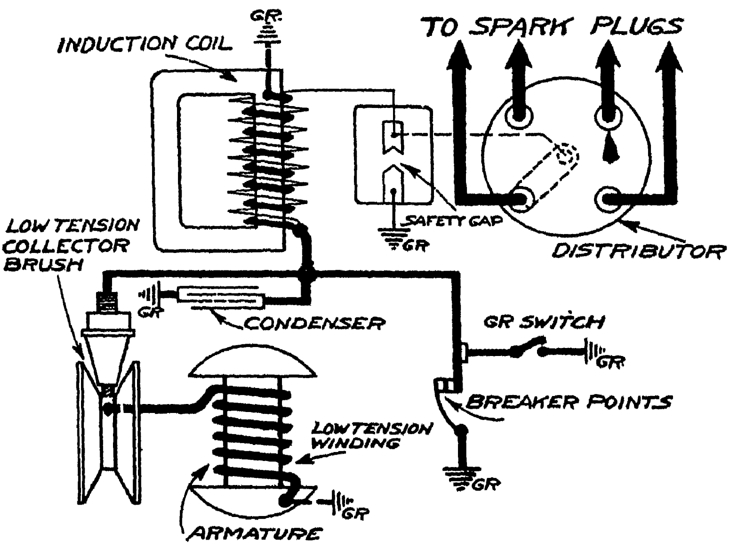


FIG. 250.—Circuit diagram of Kingston, model O, magneto.

of platinum and should have an opening of 0.015 to 0.018 in. It is also important that the contacts meet squarely and that there be proper spring tension to insure closing of the contacts at high speeds.

165. The Kingston High-tension Magneto, Model O.—The Kingston magneto, Model O, shown in Fig. 249, is used very widely on tractors. In reality, it is a low-tension magneto with a transformer coil incorporated in the arch of the magnets. A circuit diagram is shown in Fig. 250. Upon tracing the circuits it will be found that the magneto operates on the interrupted-shunt principle, the primary winding of the coil being normally short-circuited by the breaker. Since the magneto contains within itself all the essentials for high-tension ignition, such as condenser, breaker, low- and high-tension winding, distributor, safety gap, etc., the only external wiring required is the spark-plug wires, and a magneto grounding wire for stopping ignition. Even this grounding wire is omitted on many tractor installations. In this event the breaker terminal is automatically short-circuited to the ground when the breaker arm is fully retarded. The magneto is usually equipped with an impulse starter to provide easy starting of large-bore engines which are hard to crank. The platinum breaker points should be adjusted to open a maximum of 0 020 to 0.025 in.

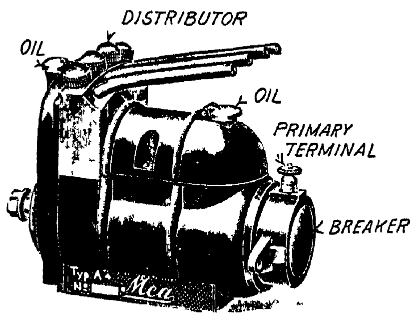


FIG 251.— The Mea magneto, type A4

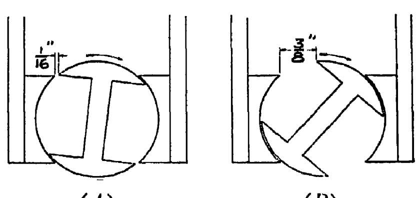


FIG 252 —Positions of shuttle type armature at moment of spark on (A) full advance and (B) full retard.

166. The Mea Magneto.—The Mea magneto, Fig. 251, which departs in several particulars from usual magneto construction, is designed to give a wide range of ignition without effecting the value of the sparking current. In the ordinary horseshoe type of magneto with fixed magnets, any change in the time of the spark means that the spark is produced at a different position of the armature with respect to the magnets, as shown in Fig. 252. This naturally limits the spark range to that part of the current wave in which suitable ignition can be obtained. The

Mea magneto shifts the magnets with the interrupter, as shown in Fig. 253, so that the armature is always in the same relation to the magnets regardless of the advance or retard of the spark-timing lever. With the standard types of Mea magnetos, the sparking range is from 45 to 70 deg. If necessary, this range can be increased. Although the Mea magneto is also offered with dual equipment for battery starting, the makers claim that the battery starting is not needed, because the magneto always takes full advantage of the armature current.

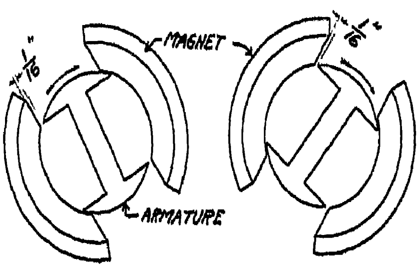


FIG. 253.—Relative position of armature and magnets at the moment of spark in Mea magneto.

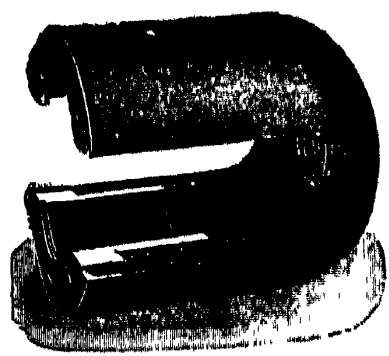


FIG. 254.—Bell-shaped magnet of Mea magneto.

The magnetic field of the magneto is furnished by a single bell-shaped magnet, as shown in Fig. 254, and is so placed that its axis coincides with that of the armature. In fact, the armature rotation inside is as illustrated in Fig. 253. Thus, if the pole pieces are shifted as a unit with the breaker, the primary current will always be interrupted at the same point, and thus the quality of the spark is not effected by advancing and retarding the spark control lever. Outside of the differences mentioned, the principle of the Mea magneto corresponds to that of other systems.

SECTION X

TYPICAL HIGH-TENSION MAGNETOS—INDUCTOR TYPES

167. Principles of the Inductor-type High-tension Magneto.—The inductor-type magneto may be classified according to two general constructions, one the *revolving-inductor type*, the other the *revolving-pole type*. In the first type the pole pieces are stationary and the magnetism is made to reverse through the winding by a rotor or inductor, while in the other arrangement

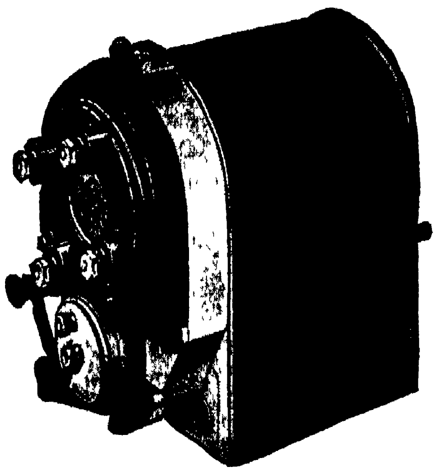


FIG. 255.—K-W high-tension magneto, model T

the pole tips of the magnets, or pole extensions therefrom, are rotated while they remain in contact with the magnets. As will be shown later, this construction causes the pole extensions to retain their constant magnetic polarity. The coil through which the magnetic flux flows has a stationary core or inductor path through which the magnetic flux is alternately reversed.

An example of the revolving-inductor type magneto is the Remy RL low-tension magneto (Sec. VIII), while the revolving-pole type is illustrated by the Ford low-tension magneto. The revolving-pole type will also be illustrated in this section in a study of the Dixie, Splitdorf, and Scintilla models.

168. The K-W High-tension Magneto.—The K-W high-tension magneto has been manufactured in two principal models. The Model T, illustrated in Fig. 255, is suitable for high-speed engines, such as are used in automobiles, trucks, and tractors, and the Model H, Fig. 256, is suitable for large, low-speed, heavy-duty engines. The K-W magneto, being of the true high-tension type, is complete in itself, requiring no external coils or apparatus other than the spark-plug wiring, the grounding wire, and the switch for cutting off the ignition. In some cases even this apparatus is not necessary, as it has a grounding contact on the magneto which short-circuits the breaker points when the timer lever is fully retarded.

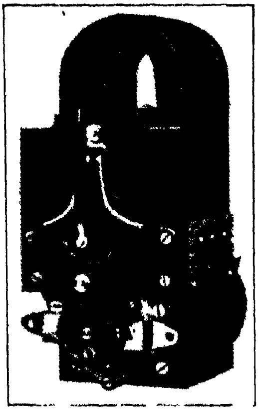


Fig. 256.—K-W high tension magneto, type H.

The construction of the rotor is shown in Fig. 257 This figure also shows, by means of arrows, the path of the magnetic flux during one com-

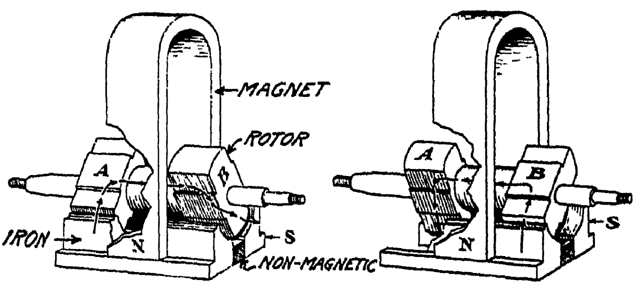


Fig. 257.—Magnetic circuits through K-W magneto with rotor in different positions.

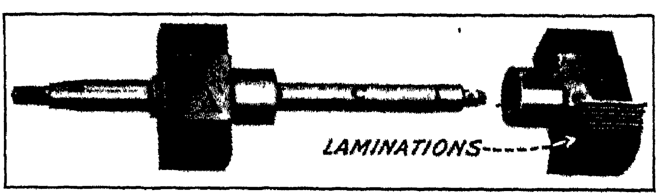


Fig 258.—Rotor of K-W high tension magneto.

plete reversal. As indicated in Fig. 258, each paddle of this rotor is built up of soft-iron laminations mounted at right angles on the steel shaft, which is supported between the bearings. Surrounding the center portion

of the rotor between the paddles, the coil, which contains both the primary and secondary winding, is wound This coil is stationary, thus no grounding brush is required as in the armature-type magneto.

A circuit diagram of the K-W magneto, type T, is shown in Fig 259. This is virtually the same as for the type H model. In this magneto,

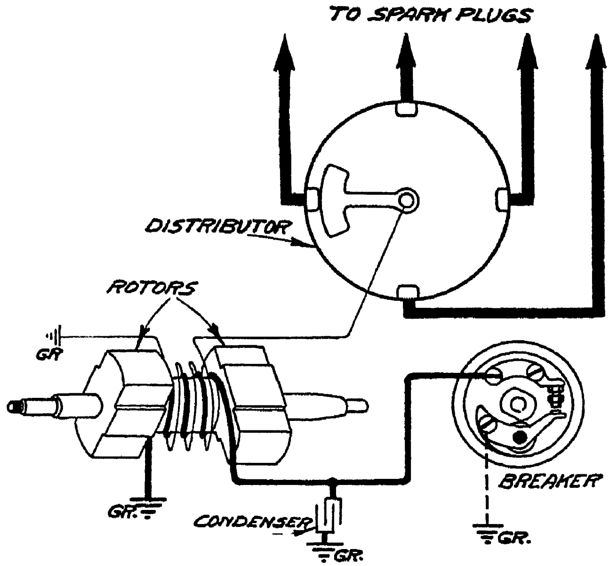


FIG 259 — Circuit diagram of K-W high-tension magneto, type T.

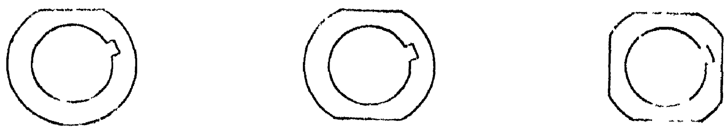
there are four complete reversals of the magnetism through the winding during each revolution; consequently, there are four pulses of current produced during each revolution of the shaft, as illustrated in Fig 260 This magneto may, therefore, be used for single-, double-, or four-spark operation without any difficulty, the only requirement being to use a cam having

FIG 260.—Current wave from K-W magneto for one revolution. Dark areas indicate periods during which the best sparks will occur upon breaker opening

one, two, or four depressions, as is shown in Fig. 261. Since this magneto can generate four pulses per revolution, it can be run at half the speed at which the regular two-pole-type magneto must be run. Or, if the manufacturer desires to have all sparks of the same polarity, only alternate pulses of current may be used, and the magneto will run at the same speed as the

regular two-pole model giving two pulses per revolution. There are advantages in this scheme.

In Sec. V, on Spark Plugs, it was pointed out that more voltage is required to jump from a blunt electrode to a sharp electrode than from a sharp-pointed electrode to a blunt one. Thus, in the K-W magneto, if each pulse of current is broken for the production of a spark, it is clear that the polarity of the spark reverses at each succeeding spark. That is, first the voltage is positive on the distributor line and the insulated spark-plug electrode, then the grounded electrode is positive on the next spark. If spark plugs should be used having electrodes of different sizes and shapes,



No. 1—Single spark. No. 2—Two sparks. No. 3 Four sparks.

FIG. 261.—Types of cams used on K-W magnetos.

when the spark would jump more easily in one direction than in the other, then, since the magneto polarity reverses in the ordinary way, every alternate plug to fire will act the same. That is, the plugs in which the sharp electrode is positive will give good sparks, while those in which the blunt electrode is positive will give feeble sparks with a tendency to misfire

In the K-W magneto, where only the alternate pulses of current are used to cause sparks, it is evident that the polarity will be the same at all plugs; consequently, the action of all plugs will be the same where the same type of plug is used in all cylinders. It is also evident that the high-tension line may be either positive or negative, as determined by the manufacturer or the operator. Thus, this magneto, when running at engine speed on a four-cylinder engine, will deliver sparks of the same polarity—this is of distinct advantage in many cases.

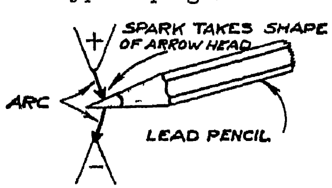


FIG. 262.—Method of determining polarity of high-tension spark terminals.

To Determine Polarity of High-tension Spark.—To determine the polarity of a high-tension spark, hold the point of a lead pencil in the path of the spark and note the characteristics of the spark. On the side of the lead pencil point next to the positive electrode the arc will take the shape of an arrow head, yellow in color. The same effect will be obtained at the negative electrode, as illustrated in Fig. 262.

Notes on Adjustment and Maintenance of the K-W Magneto.—

1. *The Safety Gap on the Model T Magneto.*—On the Model T magneto the safety gap, which is located in the back of the distributor gear, is set at 5/16 in.

2. *The breaker points* are made of platinum and should have a maximum opening of 1/64 in.

3. *The proper cam and rotor driving speeds* for K-W magnetos on the different type engines are indicated in the following table:

Number of cylinders	Speed of magneto	Using cam No.	Number of sparks per revolution of engine
1	½ Engine speed	1	1[1]
2	Engine speed	1	1
3	1½ times engine speed	1	3[1]
4	Engine speed	2	2
6	1½ times engine speed	2	3
8	Engine speed	4	4

[1] Sparks for two revolutions

4. *To check the internal timing* of this magneto, the corner of the rotor paddle should be just leaving the corner of the pole piece at the moment the points open with the timer lever on the full advance position.

5. *The distributor* is of the wipe-contact type and should be removed once a month and any carbon dust accumulation or oil cleaned off the distributor block and gear molding by wiping with a dry cloth or a cloth dampened with gasoline—*not kerosene.*

6. *The condenser* is mounted in the arch of the magnets and is so connected as to protect the breaker points against arcing and pitting.

7. *The bearings* are of the ball-bearing type and should receive three drops of oil in each of the two oil holes once a month in order to keep them properly lubricated.

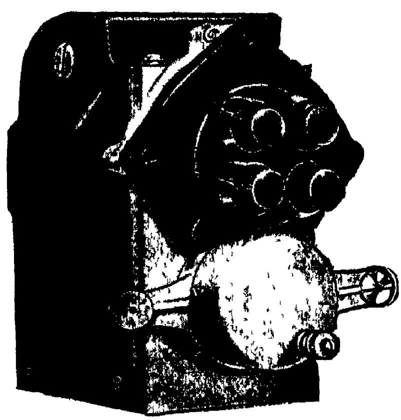


FIG. 263.—The Dixie high-tension magneto, model 46.

169. The Dixie High-tension Magneto for Four- and Six-cylinder Engines.—The Dixie high-tension magneto, a four-cylinder model of which is shown in Fig. 263, is a typical inductor-type instrument operating on what is known as the "Mason principle." This magneto has a stationary winding and a rotating inductor or rotor. Figure 264 shows a side view with the cover and one magnet removed.

The magneto consists principally of a pair of magnets, a rotor, a field structure, a winding, an interrupter, and a condenser. The

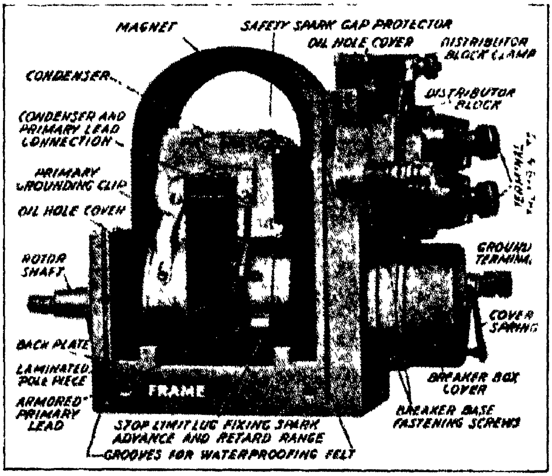


FIG 264.—Assembly side view of Dixie high-tension magneto showing principal details of construction, one magnet having been removed.

rotor, Fig. 265, consists of two revolving wings, separated by a bronze center piece. The ends of the wings are brought into con-

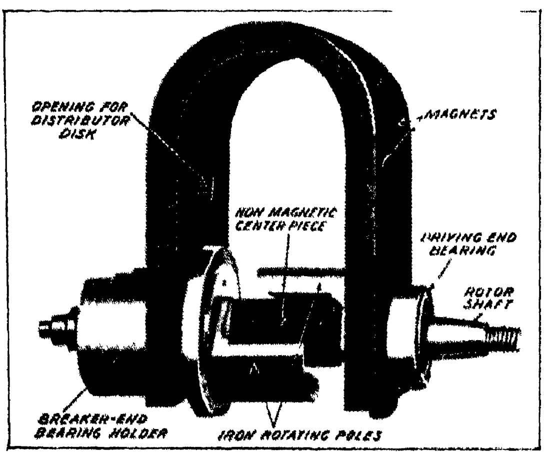


FIG. 265.—Assembly side view of magnets, rotor, and bearing holders of Dixie high-tension magneto.

tact with the poles of the magnets as shown, therefore, they bear the same polarity or magnetism as the poles of the magnets

with which they are in contact. This polarity of the wings is always the same, as there is no reversal of magnetism through them. The rotor is surrounded by a field structor, Fig. 266, which carries laminated pole extensions on which the winding with the

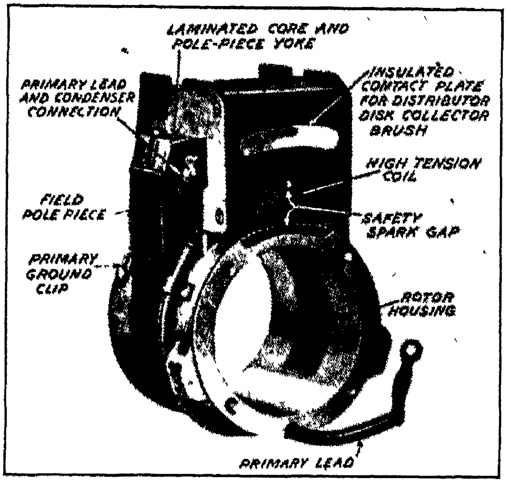


FIG. 266.—Interrupter-end view of rotor housing and coil of Dixie high-tension magneto showing insulated distributor-brush contact segment and safety spark gap

laminated core is mounted. The path of the magnetism is shown in Fig. 267.

As the rotor revolves, the magnetic flux penetrates the core of the winding, first in one direction and then in the other, according to the position of the rotor in relation to the poles of the field structure as shown in Figs. 268, 269, 270, and 271. Figure 269 shows the rotor in such a position that the flux enters wing N, passes through the core C, and returns to wing S of the rotor. Figure 271 shows the flux passing through the coil in the reverse direction.

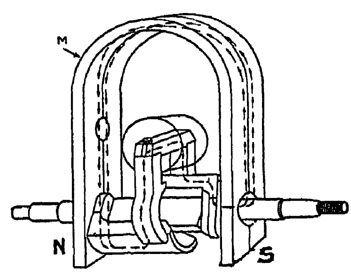


FIG. 267.—Path of magnetism through Dixie magneto rotor and coil.

The greatest intensity in the primary circuit occurs when the rate of change in flux or magnetic lines of force through the core is a maximum. This occurs when the rotor is in the position

shown in Fig. 270. In this position, the rotor wings have just reversed the direction of flux through the core, the gap between the trailing wing corner and the pole piece being from 0.015 to 0.035 in., preferably 0.020 in. Consequently, the interrupter

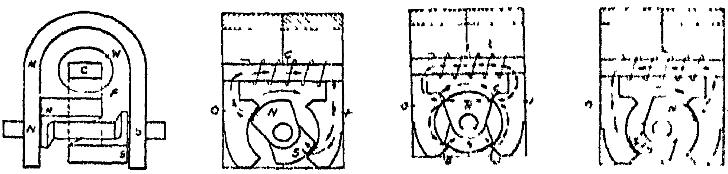


FIG. 268. FIG. 269. FIG. 270. FIG. 271.
FIGS. 268–271.—Showing the principle of the Dixie magneto.

contact points should be adjusted to break the primary circuit when the rotor is in this position.

A circuit diagram of the magneto is shown in Fig. 272. The primary circuit is of the interrupted-primary-current type.

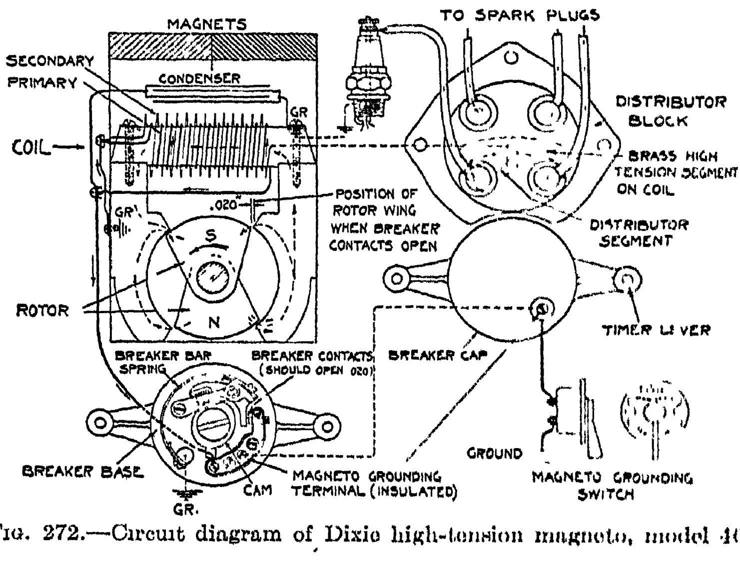


FIG. 272.—Circuit diagram of Dixie high-tension magneto, model 46.

The breaking of the primary circuit induces a high-voltage current in the secondary winding, this current being directed to the proper spark plug by a distributor driven by a gear on the rotor shaft. The condenser, one terminal of which is connected to the insulated end of the primary coil and the other terminal grounded to

the magneto frame, is mounted on the top of the coil, as shown in Figs. 264 and 272.

One of the outstanding features of the Dixie magneto is the shifting of the pole pieces with the timing lever upon advancing and retarding the spark. This permits the breaker to interrupt the primary circuit when the primary current is flowing at its maximum, thus causing a spark of maximum intensity at all positions of the breaker.

Since the coil windings are not on a revolving armature, the interrupter is built like that for a low-tension magneto, *i.e.*, the interrupter mechanism is mounted on the interrupter housing and the cam revolves with the rotor shaft. This construction permits the adjustment of the contact points with the engine and magneto running. The contacts are made of platinum and should be adjusted to open 0.020 in.

Magneto Switch.—The Dixie magneto switch is shown in Fig 272. An insulated terminal, which is connected to the insulated end of the magneto primary winding, extends through the magneto breaker cover. This terminal is connected to a grounding switch by which the primary winding can be grounded or short-circuited, and ignition prevented. The wire leading from the magneto is attached to one of the terminals on the back of the switch. The other terminal on the switch is grounded. The ignition is locked when the switch lever is in the "Off" position, and when in this position the switch lever may be taken out to prevent the operation of the magneto.

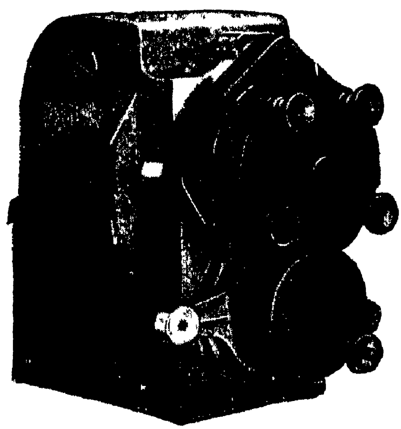


FIG 273.—Splitdorf "Aero" magneto.

170. The Splitdorf "Aero" Magneto.—The Splitdorf "Aero" high-tension magneto, Fig. 273, closely resembles the Dixie magneto in external appearance. As a matter of fact, the principle of operation of the Dixie magneto has been modified and improved upon in the Aero magneto. The principal differences are in the rotor and in the shape of the pole pieces. The rotor of the Aero magneto for four-, six-, and eight-cylinder engines has four lobes or shoes, as shown in Fig. 274, while the Dixie rotor

has but two lobes. The path of the magnetic flux through the coil and the rotor is shown in Figs. 275 and 276. From these figures it can be seen that the pole pieces in the Aero magneto do

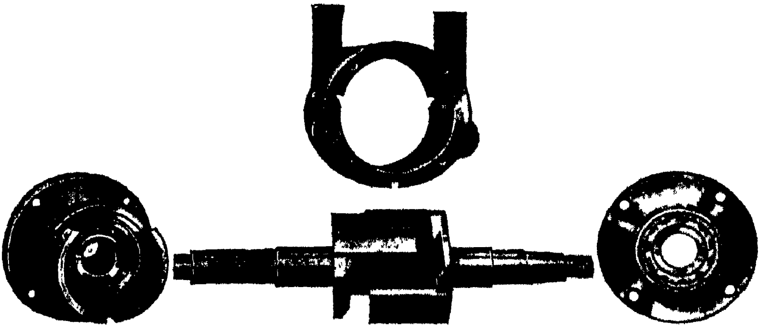


Fig. 274.—Rotating poles, bearings, and field of Splitdorf "Aero" magneto

not extend completely around the rotor as in the Dixie magneto, but are confined to the upper quarters of the circle.

With this type of rotor construction the magnetic flux reverses through the winding four times every revolution. Only one-half of these current impulses are used, however, to produce sparks at the spark plugs.

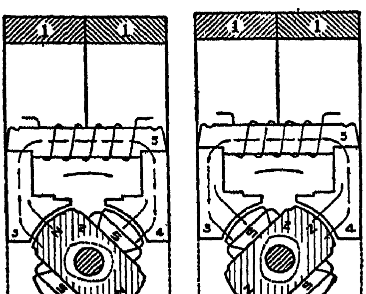


Fig. 275. Fig. 276.

Figs. 275 and 276.—Showing path and reversal of magnetism through Splitdorf "Aero" magneto during one-fourth revolution.

The current wave of the Aero magneto is similar to the wave shown in Fig. 277. In this figure it will be seen that, of the four current impulses produced per revolution of the rotor, two are drawn above the axis and two are drawn below. The impulses above the axis are called positive loops and indicate that the current is flowing in a given direction through the circuit. The impulses below the axis are called negative loops and indicate that the current is flowing in the opposite direction through the circuit. The high-tension surges of current produced in the secondary circuit by the opening of the breaker points also reverse in direction so that the high-tension current will jump from the center electrode of the spark plug to the shell in one plug, and from the shell to the center electrode in another plug at the next spark. In the Aero magneto, the breaker points open only on the positive loops, thus creating current surges in one direction only in the high-tension circuit. (The circuit diagram and breaker adjustments are the same as for the Dixie magneto.)

With this construction, the high-tension current produced in the secondary winding, and delivered to the spark plugs, is uniform, *i.e*, the high-tension current from the magneto to the spark plug flows in one direction only, and this direction is such that the current always jumps from the shell or grounded electrode to the center or insulated electrode. The manufacturers claim that this constant direction of the spark insures

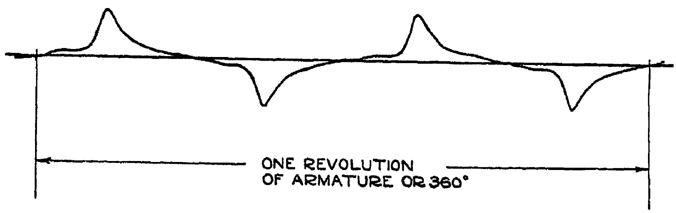


FIG 277.—Short-circuit current wave from typical inductor high tension magneto giving four impulses per revolution.

a spark of great intensity, uniformity, and superior igniting power. This is particularly true when spark plugs having a smaller or sharper grounded electrode are used

171. The Teagle Magneto—Model 77.—The Teagle magneto, Fig. 278, is a direct high-tension magneto of the inductor type, the current being generated by the rotation of an unwound rotor which shifts the magnetic flux first through and then around a high-tension coil or winding. The path taken by the magnetic lines are shown by the arrows in Figs. 279*A* and *B* respectively.

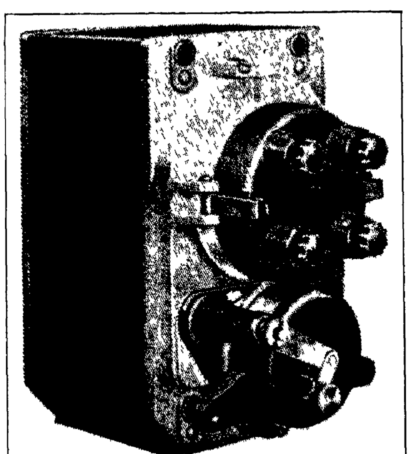


FIG. 278.—The Teagle magneto, model 77.

Principles of Operation.—When the rotor is in the position marked *A*, Fig. 279*B*, the entire flux from the magnets (the magnets are of the straight type) passes down through coil and base *B*—the circuit being completed through the permanent magnets at the sides. As the rotor revolves, it comes into position *C*, Fig. 279*A*, in which position the flux flows through the by-pass *D* instead of through the main pole. Thus the flux is cleared outside of the coil, completing the circuit through the rotor and the by-pass, returning through the permanent magnets at the sides, as before indicated.

The two windings of the coil are connected to each other and to the ground, the circuits being as shown in Fig. 280. One end of the primary winding is connected to the breaker, while the other end is grounded.

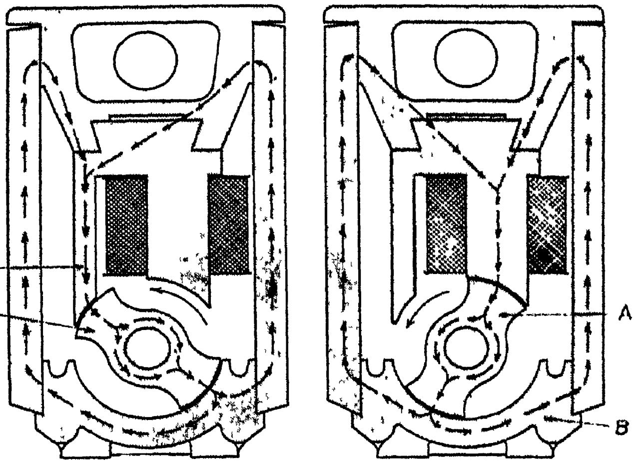


Fig. 279.—Path of magnetic flux in Teagle high-tension magneto.

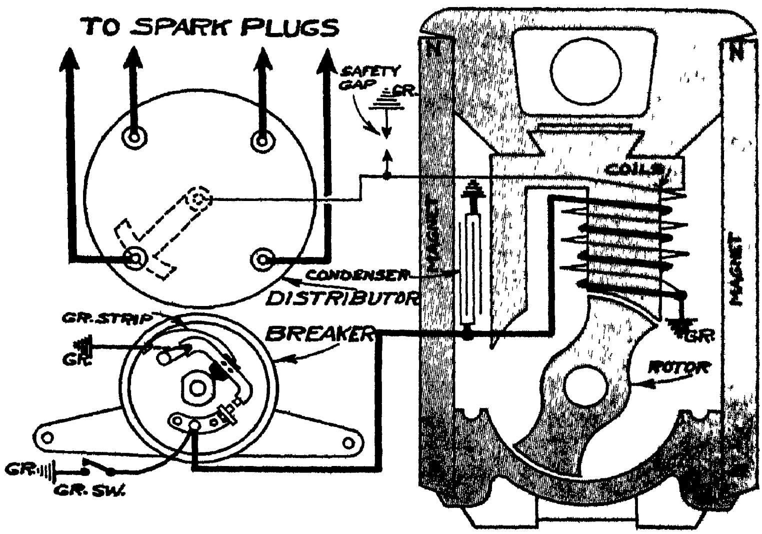


Fig. 280.—Circuit diagram of Teagle magneto, model 77.

As may be seen from Fig. 280, the breaker is of the non-revolving type, the cam being mounted on the end of the rotor similar to the common construction in low-tension magnetos. When the contact points are

closed, the primary winding is short-circuited through them and the entire magnetic flux is passing through the coil.

As the rotor moves and the flux decreases in the coil, the cutting of the winding by the changing lines of force sets up a current in the primary winding, which, as is stated above, is short-circuited through the breaker points. When the current has reached its maximum value the breaker points open, breaking the interrupted current and demagnetizing the core. This induces a high voltage in the secondary winding, which in turn produces a spark at the plug lined up to fire. The continued movement of the rotor from this point causes a still further decrease of the flux in the coil, and the induced voltage causes current to flow through the high-tension winding. The spark-plug gap over which the spark has jumped thus produces an arc, resulting in ignition. The value of the ignition spark consists not only in the initial jump, which is merely a breaking down of starting conditions between the points of the spark plug, but also in the heavy follow-up current or arc produced by the continued movement of the rotor.

The breaker points are protected against excessive sparking by the condenser connected in parallel with them. The condenser is located on the side of the small coil. It is claimed that the coil and condenser are so well balanced that the arc is practically eliminated, giving very long life to the points. The breaker points should be adjusted to open a maximum distance of 0.015 in.

The rotor is supported by ball bearings and the distributor gear shaft is supported on a plain bearing. Each bearing while in use should be oiled about every 1,000 hours with a good light machine oil (never cylinder oil). The oil holes are located at both ends of the magneto.

The timing of the magneto, both internal and to the engine, is similar to those of other makes.

172. The Scintilla Magneto, Type AG4.—The Scintilla magneto, Fig. 281, is of Swiss manufacture. It is of the inductor type, without movable windings, and, while it comprises the same parts as any other magneto, considerable ingenuity has been displayed in the arrangement of details whereby a number of advantages in manufacture, care, and maintenance are secured. A sectional view is shown in Fig. 282, while Fig. 283 shows it disassembled.

The rotating part, or rotor, Fig. 284, is a bell-shaped permanent magnet which has the driving shaft forged integral with it. The pole pieces of this magnet are laminated, the laminations being slipped over extensions of the forging and held in position by two screws on each leg of the magnet. These screws also hold in place a bronze ring over the ends of the poles with which the shaft, at the interrupter end, is formed integral. The rotor is supported in ball bearings at both ends.

The magnetic circuit is completed by two laminated pole shoes set into the die-cast aluminum alloy housing and a laminated core extending through the stationary coils. The core is of sub-

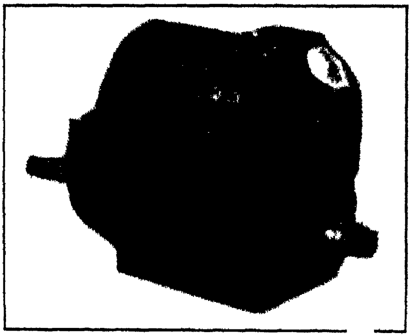


Fig. 281.—The Scintilla magneto, type AG4.

stantially square section with rounded corners; its ends are slotted and it is fastened to the pole shoes at each end by a machine screw which passes through the slot and into the pole

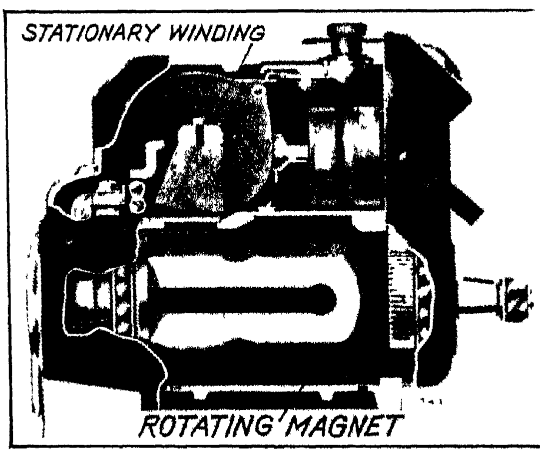


Fig. 282.—Sectional view of Scintilla magneto showing rotating magnet and stationary winding.

shoe. Both the primary and the secondary coils are wound on this core. The condenser is also incorporated in this unit. As both windings are stationary, there is no need for a collector ring with its attendant difficulties.

A circuit diagram of this magneto is shown in Fig. 285. As may be seen, one primary lead is grounded to the core and the other is brought out to a strip brass connector which extends

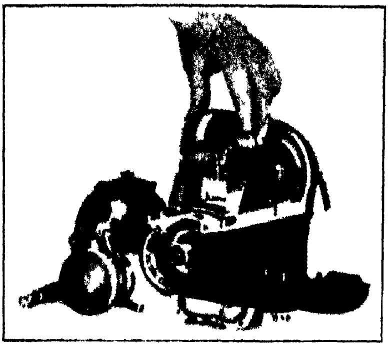


FIG. 283.- Method of removing coil in Scintilla magneto.

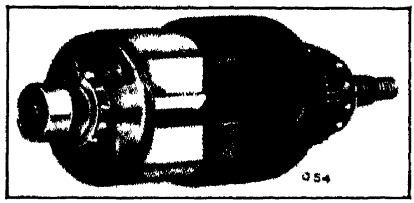


FIG. 284 —Rotor type magnet used in Scintilla magneto.

halfway around the coil. At the top this connector makes contact with the low-tension terminal, from which terminal connection is made to the ignition switch, by which the primary

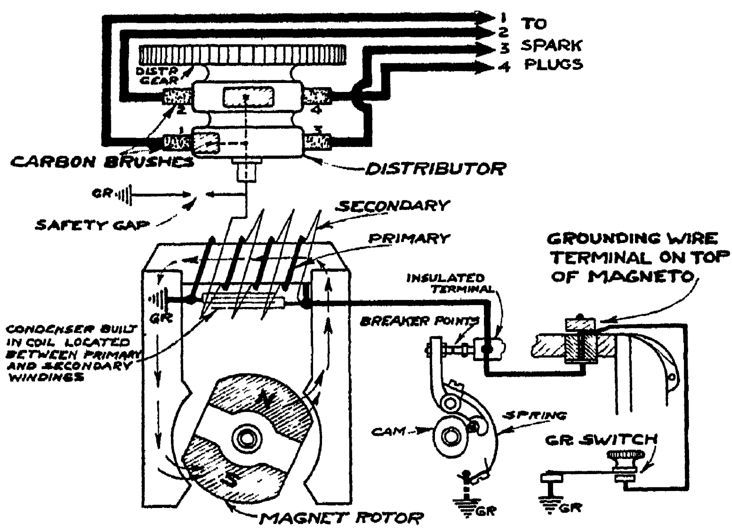


FIG. 285.—Circuit diagram for Scintilla magneto.

winding of the magneto can be short-circuited and the operation of the machine stopped. At the interrupter end there is a similar connection to the insulated block of the interrupter. This

is a sliding contact, the interrupter block moving relative to the connector when the timing of the spark is changed. One part of each of these two connections is spring-supported, so that a good, firm contact is obtained under all conditions. The condenser is wound on the coil between the primary and secondary windings. This is an unusual construction.

The Interrupter.—The interrupter, Fig. 285, consists of a cylindrical frame which fits into a corresponding seat in the housing and is locked in place by a bayonet lock. The timing lever is formed integral with a cap over the interrupter, this cap being held by a centrally located machine screw and a pair of dowel pins. There are eight equally spaced holes in a circle in the interrupter frame, whereby the timer lever can be placed in any of eight angular positions. This makes the magneto easily adaptable to different engines. There is a special locking ring on the interrupter with a radial lever which, when it is desired to insert the interrupter in position on the magneto, must be turned relative to the frame against the torsion of a spiral spring. When in proper position, the interrupter can be pushed into place in the direction of the rotor axis. The lever on the locking ring is then released and the ring is snapped back by the spring, locking the interrupter in place.

For a four- or six-cylinder magneto, a two-lobed cam is mounted on the rotor shaft. This cam acts with a bell-crank-shaped interrupter lever fitted with a fiber cam follower and a fiber bushing. The platinum contacts of the interrupter are always located on top, where they can be inspected easily and are protected from oil accumulations. The contacts should open 0.015 to 0.020 in.

A feature found on few if any other magnetos is that the timer is under the influence of a coiled spring which tends to bring it back to the retarded or late ignition position. If the driver is careless in setting the spark control, there is little danger of the engine's racing because of advanced spark. The timing range is 35 deg.

The Distributor.—The distributor, contrary to conventional practice, is located at the driving end. This position is possible because the high-tension terminals are not at the end of the magneto, but on top of it. An eccentric adjustment is provided on the distributor gear so that the center distance of the gears can be closely adjusted for correct mesh and quiet running. The distributor shaft is made with a disc which sets into a circular recess in the end plate of the housing and is held in place by two machine screws passing through arc-shaped slots. The shaft or stud is eccentric with relation to the disc, so, by loosening the retaining screws and turning the stud and disc through a small angle and then tightening the screws again, the distributor gear can be brought closer to or moved farther away from its pinion.

The distributor itself is in the form of a drum with two metal sectors embedded in a piece of molded insulation. The contact sectors are offset

from each other in an axial direction and are spaced 90 deg. circumferentally. There are four carbon brushes (in a four-cylinder magneto) bearing on the surface of the distributor drum, two being carried side by side in each brush holder.

Injury from Over-oiling Impossible.—There are oil holes with snap covers at each end. Owing to the location of the coils and the interrupter points, it is impossible to injure the machine by over-oiling The snap cover over the oil hole at the driving end also covers a timing window.

Timing.—In timing the magneto, the rotor is turned until a figure 1 appears centrally in the distributor window. The engine crankshaft is then turned until the piston in No. 1 cylinder is in the top dead-center position at the beginning of the firing stroke. With the rotor and crankshaft in these positions the gears are fastened to their shafts. All the secondary terminals are plainly marked as to the cylinder to which they are to be connected, and the direction of rotation is indicated by an arrow on top of the magneto.

173. General Rules for Magneto Ignition Timing.—The same methods are generally used in timing practically all types of high-tension magnetos used on automobiles. The crank of the engine should be turned until one of the pistons, preferably that of cylinder No. 1 is on upper dead-center position at the end of the compression stroke. With the timing lever in full retard position and the magneto-driving coupling or gear disconnected, the driving shaft of the magneto should be rotated in the direction in which it will be driven. The breaker should be observed closely, and, when the platinum contact points are about to separate, the drive gear or coupling should be secured to the driveshaft of the magneto. Care should be taken that the position of the magneto shaft is not altered when the nut is tightened to secure the gear or coupling. After this is done, the magneto should be fastened to its base. The distributor block should then be removed to determine which terminal of the block is in contact with the bronze sector of the distributor disc. The terminal found in contact should be wired to the cable leading to cylinder No. 1, and the remaining cables to the remaining cylinders in accordance with their sequence of firing, remembering that the distributor runs in the opposite direction from the rotor of the magneto.

SECTION XI

SPECIAL IGNITION EQUIPMENT

174. Principles of the Oscillating-type Magneto.—On large engines, particularly of the stationary, low-speed type, it is sometimes inconvenient or impossible to turn the engine fast enough by hand to secure a satisfactory ignition spark from the ordinary rotating type of magneto driven at normal speeds. It was for

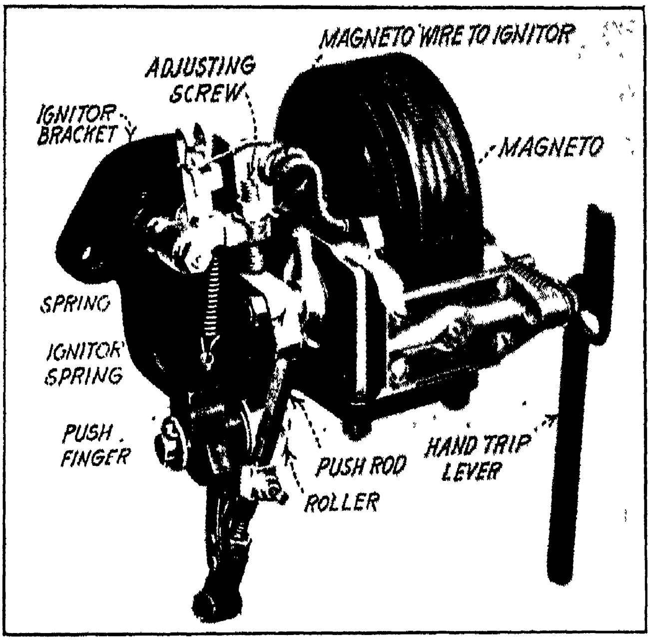


FIG. 286.—Webster tri-polar oscillator magneto with ignition bracket and trip mechanism.

this service that the oscillator type of magneto was developed. In this type, the armature or rotor (the magneto may be of either the armature-wound or inductor type) is arranged to rotate or oscillate through a part of a revolution against heavy spring tension, and is then released and snapped back to its normal position instead of rotating through complete revolutions as in the usual low- or high-tension magneto.

As the springs draw the armature back to its original position, the high momentary armature speed causes sufficient current to be produced in the windings so that, if the ignition or breaker is timed to interrupt the circuit when the current has reached full value, suitable ignition may be supplied to the engine, even though the engine speed is very low.

The oscillator magneto may be either of the low-tension type, in which case it operates in conjunction with a make-and-break type of igniter, or it may be of the high-tension type, in which case it provides ignition through the usual spark plug.

175. The Webster Tri-polar Oscillator.—The Webster tri-polar oscillator, Fig. 286, is, in principle, a low-voltage magneto

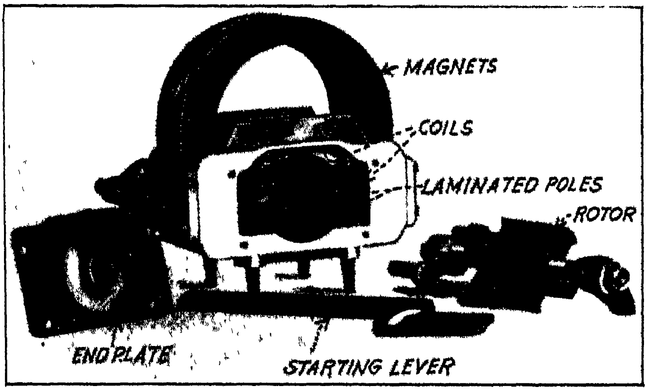


FIG. 287.—Disassembled view of Webster tri-polar oscillator magneto.

of the inductor type, and operates in conjunction with a make-and-break igniter carried at one end of the bracket on which the magneto is mounted. The entire unit is usually bolted to the engine cylinder head so that the igniter points extend through the cylinder head into contact with the gases. Both the igniter and the rotor are usually operated by a push rod, the movement of which is timed with the crankshaft.

A disassembled view of the Webster oscillator magneto, showing the principal parts, is shown in Fig. 287. The coils are stationary, while the rotor is of the four-armed type, Fig. 288 consisting of a cross-shaped set of steel stampings clamped on a shaft. Special stampings, which have the shape of the letter "E," are used for the magnet pole pieces, as may be seen

in Fig. 287. Over the center arms of each of the letter-E stampings, which form the pole pieces, are wound the coils, the two being connected in series so that their voltages are added.

Operation.—The principles of this magneto can be readily understood from a study of Figs. 289 and 290. The rotor is oscillated through an angle of about 30 deg. against the action of the two heavy springs, at which time the

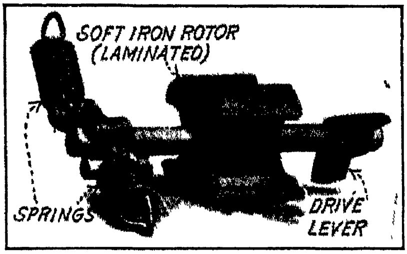


FIG 288.—Rotor and spring assembly for Webster oscillator.

rotor arms are in the horizontal and vertical positions, respectively, as shown in Fig. 289. In this position, the magnetic flux passes through the cores which carry the winding. The rotor is then released to return to its normal position, the rotor arms taking the position indicated in Fig. 290. As the rotor returns, the magnetic flux is shifted to the paths indicated by the arrows, thus causing the lines of force to cut the winding, inducing a voltage in it.

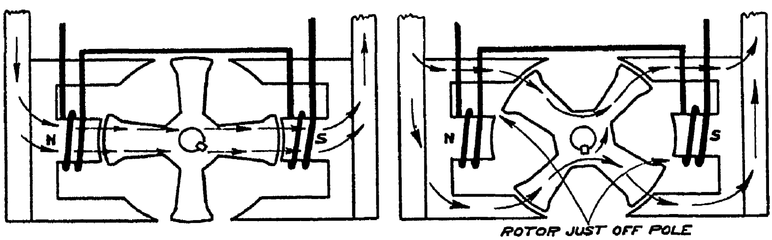


FIG. 289. FIG 290.

FIGS. 289 and 290.—Path of magnetic flux through Webster magneto.

When the driver lever (which holds the rotor in the oscillated position against the spring tension) is released, the rotor returns rapidly to its original normal position, making several oscillations before it finally comes to rest. When it is at rest, the magnetic flux is as shown in Fig. 290. As the first oscillation is much more rapid than the succeeding ones, it is the first oscillation which should be considered for ignition purposes. This is illustrated in Fig. 291, which shows the short-circuit current wave produced after trip-off. This curve illustrates clearly how the current rises and falls rapidly, the current produced during the first oscillation being over twice the value of the one following.

Attached to the bracket on which the magneto is mounted is the make-and-break igniter block, as shown in Fig. 286 Thus, the whole apparatus is made into one unit. The flanged roller forms a support for the push rod, holding it in such a position that it engages the upper end of the magneto push finger. The lower end of this same push finger hangs against the tip of a screw attached to the arm of the movable electrode On the push rod is an adjustable wedge, which, at a certain point in the travel of the rod, rides up on the roller, lifting the rod out of engagement with the push finger.

On the outer end of the movable electrode there is keyed an arm known as the electrode arm. This carries an adjusting screw the end of which just touches the tail of the push finger when the magneto springs are in the straight-line position The adjusting screw is provided to compensate for any wear of the igniter points.

On the firing stroke of the engine, the push rod moves toward the magneto, engaging the push finger and rotating the inductor through an angle of

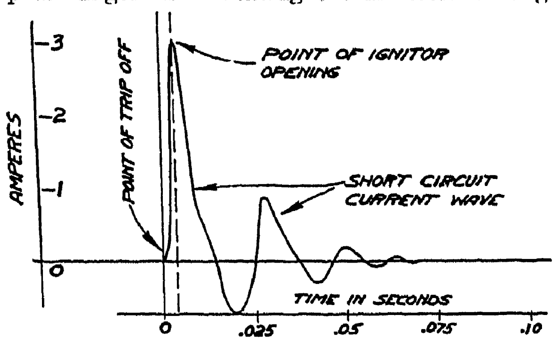


FIG. 291 —Current wave produced by Webster tri-polar magneto, model K-40.

about 30 deg., as illustrated in Fig 289. By this time the wedge has mounted the roller, causing the push finger to be released. The springs on the magneto then recoil at high velocity, generating the current wave described above. This current is broken when at its maximum intensity by the igniter contacts opening through the action of the lower end of the push finger, striking against the electrode arm-adjusting screw.

The control lever is pinned to the eccentric on which the push-rod roller bears, and by moving the lever in one direction the eccentric is raised, thereby allowing the push rod to release early. This is the advance, or running, position. By moving the lever in the other direction, the eccentric is lowered, permitting the push rod to engage the push finger for a longer period. This is the retarded, or starting, position.

For starting on compression, or from a standstill, a "starting lever" is furnished with each magneto and is permanently attached to it. This enables the user to operate the magneto entirely by hand in any position of the engine crank. After once having the priming charge and the proper compression in the cylinder, the engine can readily be started without cranking by backing the flywheel up against compression and snapping off

the magneto with this lever. In using Webster tri-polar oscillators, batteries are unnecessary, as even the larger sized engines can be started as described. The lever also serves as a timing gage, which gives the correct position and number of degrees through which the magneto should be operated.

Points to Consider in Adjusting the Magneto.—Since the current wave produced is so sharp, the repairman must be very careful in making adjustments in order that the igniter points may open at the time of best spark. This adjusting can be done by taking the apparatus from the engine and trying it out by the hand lever. Furthermore, because the slightest wear on the points will draw the point of break to an earlier position, it is necessary to make frequent adjustments instead of allowing the magneto to operate without attention for long periods Many people misjudge the value of this machine on this account. They do not understand how to set the break and therefore assume that the magnets have lost their magnetism should the spark become feeble

176. The Sumpter Plug Oscillator.—A general view of the Sumpter plug oscillator is shown in Fig. 292. This outfit is also a combined unit, including a magneto and an igniter in one assembly. This machine is of the bipolar, shuttle-wound-armature type, and has many interesting and valuable features. Like the Webster tripolar oscillator, it has a hand-operated trip lever by which it may be readily tested when off the engine. In this machine the thrust of the push rod is taken up by an entirely separate bearing, which then transmits the movement by a small crank to the rotor. In this way the bearings of the magneto have merely to withstand the strains of the oscillating movement, instead of the thrust in addition.

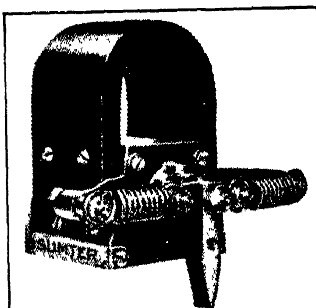


FIG. 292—The Sumpter plug oscillator.

One terminal of the winding is grounded, as usual, and the other terminal is brought around directly to the insulated terminal of the igniter. The closed-circuit-type breaker is used, and, like the Webster outfit, when the rotor swings back after its roll-over, a hammer strikes the breaker trip lever, which opens the circuit at the proper time. Unlike the Webster, this magneto generates a flat-waved, short-circuit current, as may be seen from a study of the current wave shown in Fig. 293. In fact, it is not necessary for the breaker to open at exactly a certain

point in order to get a good spark. It is claimed that the outfit is so well designed that it will not have to be retimed or adjusted to take up wear for the entire life of the points.

A further study of the current wave shows that there is a fairly wide range in which the igniter can open and yet produce a good spark. This eliminates the necessity for the operator's setting adjusting screws. The only thing,

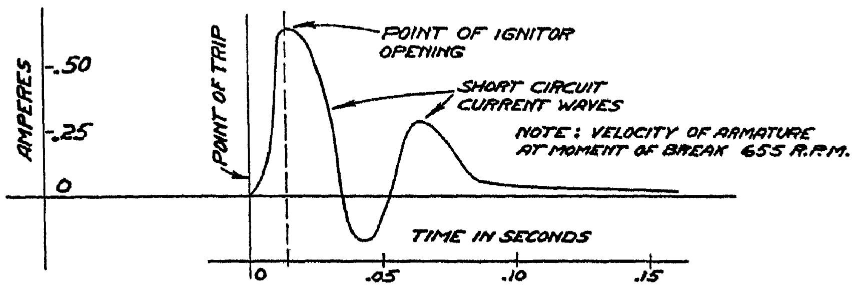


FIG. 293.—Current wave of Sumpter plug oscillator, type C.

then, that must be set is the point of the trip-off for the range of operation desired. In fact, the factory sets the equipment so that it will trip off between the limits of good operation, while the breaker points wear from full size to the minimum allowed. Therefore, to put this magneto into first-class condition, after the points have worn, merely requires replacing the breaker points and filing them into contact in the usual manner.

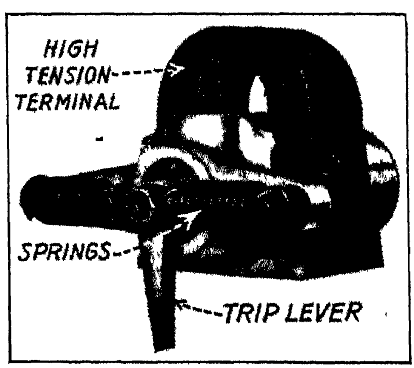


FIG. 294.—Bosch high-tension oscillator magneto, 1922 model.

177. The Bosch High-tension Oscillator Magneto.—The high-tension oscillator magneto, Fig. 294, manufactured by the American Bosch Magneto Corporation, is a typical example of a high-tension oscillator magneto of the armature type. As will be noted, two heavy coil springs hold the H-type armature normally

in a vertical position as shown in Fig. 295. When the tripping device bears against the trip lever of the magneto, the armature is oscillated approximately 30 deg. from its normal position, as shown in Fig. 296. This figure also shows the path of the magnetic flux through the armature. In this position the trip lever is released and the armature quickly returns to its normal vertical

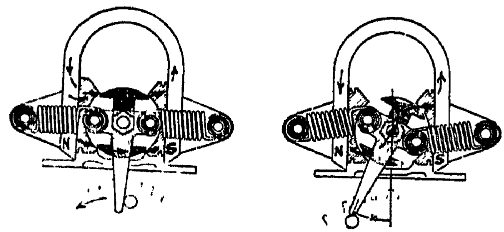


FIG. 295. FIG. 296.

FIG. 295 Position of Bosch oscillator armature in normal position.
FIG. 296.—Position of Bosch oscillator armature in oscillated position

position, Fig. 295, by the action of the two springs. Thus, a partial rotation at high rotative speed is given the armature, irrespective of engine speed. With proper spring action the full electrical capacity of the magneto is thus obtainable.

As will be noted in Fig. 297, which shows a circuit diagram of the magneto, the armature corresponds to that of the usual

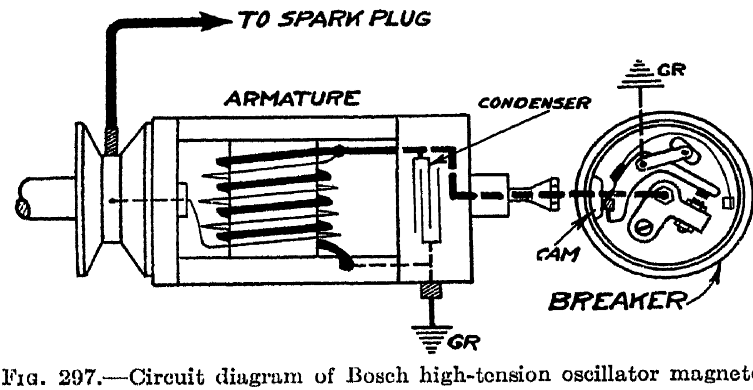


FIG. 297.—Circuit diagram of Bosch high-tension oscillator magneto.

Bosch magneto, the most important difference being that the breaker housing contains only one steel cam for actuating the breaker instead of the two usually found in the standard magneto. The adjustment of the breaker points also corresponds to standard Bosch practice, in that they should be adjusted to open about

0.015 in., when the breaker buffer is riding on the highest point of the cam. The breaker should be timed to open when the corner of the armature is just leaving the corner of the pole pieces, which is approximately the normal vertical position of the armature when under spring tension.

The bearings of the magneto are of bronze bushings instead of the usual ball bearings and are removable. The bearing at the trip-lever or collector-ring end is subjected to severe duty but, should it become worn, it may be readily taken out by removing the three screws which hold it and be replaced by a new one. The magneto should not be operated if the bearings become badly worn, as the armature may strike the pole pieces and cause further damage.

178. Methods Used to Improve Magneto Ignition at Cranking Speeds.—Because of the low rotative speed at which the magneto armature turns during the cranking of the engine, the voltage generated by it is often so low that it is difficult to start the engine on "Magneto," especially if the compression is high. In order to get around this difficulty, various ways have been devised to improve the quality of the secondary spark during the cranking period. These may be divided into two classes: (1) those in which battery current is utilized either to assist the magneto current or to provide current for the spark, and (2) a mechanical auxiliary apparatus or *impulse starter,* the object of which is to give the armature a higher rotative speed during part of the revolution, thereby enabling the magneto armature to deliver a higher voltage and current.

In the study of the various low-tension dual magneto ignition systems, it is found that a set of dry cells or a storage battery could be used during cranking for the production of ignition by simply throwing the switch to the "Battery" position. It should also be remembered that the magneto breaker and the distributor function the same regardless of the source of current. When a high-tension magneto is used, it is not so simple. In the high-tension magneto it should be remembered that the insulated side of the breaker is permanently connected to the primary winding of the magneto, while the other side is grounded. Thus, if a battery is to be used to assist the magneto current at low speeds, so as to produce a better spark and is to be connected similar to the low-tension magneto system, the construction must be such

that the direct current produced by the battery will not interfere with the alternating current generated in the magneto winding when the armature is rotated. The schemes commonly used are as follows:

1. *The Duplex or booster coil system*, in which a coil is connected in the battery circuit outside of the magneto, the magneto breaker cover being provided with a two-segment commutator. An example of this is the Simms installation on the 1915 and 1916 Maxwell.

2. *The auxiliary vibrator system*, in which a special vibrator is connected in the magneto and battery circuit.

3. *The high-tension dual system*, in which a separate breaker is employed for interrupting the battery current.

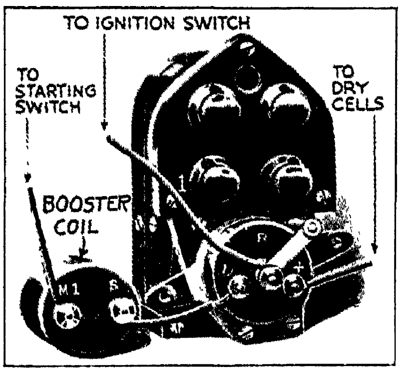


FIG 298 Simms high-tension magneto with booster coil used on Maxwell, 1915 and 1916 models.

179. The Simms High-tension Magneto with Booster Coil.—The Simms high-tension magneto, Fig. 298, is a good example of the duplex or booster-coil type of system, in which battery current is used to supplement the magneto current for obtaining better ignition sparks at low rotative speeds.

This system was installed as standard equipment on the Maxwell car from 1915 to 1917 inclusive. A circuit diagram of the system is shown in Fig. 299. From this figure, it may be seen that a simple inductive or kick coil, containing a core and single winding, is connected between the switch (which is incorporated in the cover of the starting switch), and No. 1 terminal on the breaker cover. The other terminals on the breaker cover, marked + and *R*, connect to the positive terminal of the dry cells and to the magneto grounding switch, respectively.

In a study of the breaker, Fig. 299, it will be found that two brushes are mounted on the breaker plate, one connecting to the insulated side of the breaker and the other to the ground. The brushes make rubbing contact on the two insulated metal segments on the inside of the breaker cover. These segments connect with terminal 1 and + respectively. Terminal *R* connects with the insulated side of the breaker at all times, thereby providing a means of grounding the magneto primary winding when ignition is to be prevented. Four or five dry cells are usually used, connected as shown. The switch which

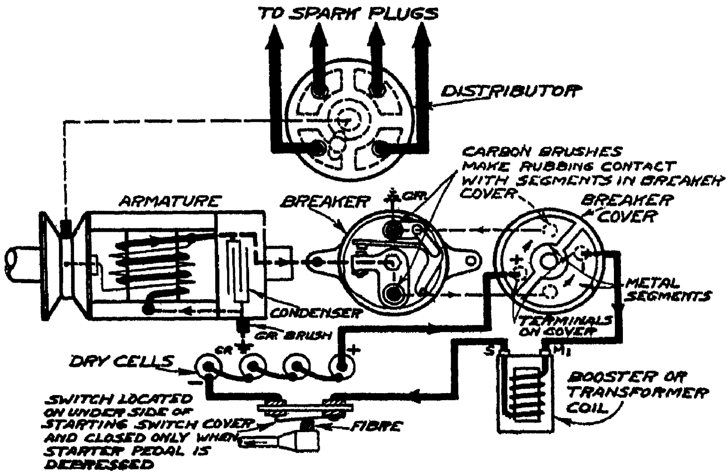


FIG. 299.—Circuit diagram of Simms magneto with booster coil

operates the dry-cell circuit is in connection with the starting switch, and is closed only while the starting pedal is depressed, causing the starting motor to operate. With this switch closed, the current from the dry cells flows through the magneto, booster coil, and switch, thus completing its circuit.

Since the current generated in the magneto armature is alternating in direction, and since the battery current is direct and flows in one direction only, the battery current would tend to oppose, if not kill entirely, the current generated in the armature during half of each revolution. For this reason the two-segment commutator and brushes mentioned above are used. As the two brushes revolve, they make contact, first with one segment, then with the other, the result being that the current from the dry

cells is converted into alternating current as it passes through the primary magneto winding. If the polarity is proper, the current from the dry cells will be directed through the magneto winding in the same direction as the generated magneto primary current, thus being in step with it. If the polarity of the dry cells should be reversed, however, it is obvious that the battery current would oppose that generated in the armature during each half revolution, thus tending to kill the action of the armature and resulting in no spark at the plugs.

The breaker, as may be seen from Fig. 299, is similar to the breakers of the Bosch and Eisemann. It is of the rocker-arm type and revolves with the armature. The only difference that might be mentioned is that the cams are a little longer, thus increasing the period of breaker opening. It should be remembered that the breaker points on any high-tension magneto remain normally closed, at least long enough to allow the generated current to build up to full value.

Principles of Operation.—The theory of operation of the system during the cranking process is as follows: As the armature revolves, say from a horizontal to a vertical position (which may be considered the generating period), the breaker points remain normally closed, thus short-circuiting the primary winding and allowing the generated current to build up to full value. During this period, the current from the dry cells flows through the closed breaker points, through the booster-coil winding, and back through the switch to the negative side of the dry cells, the only effect being to magnetize the core of the booster coil. However, at the moment the breaker points open, interrupting the primary-armature circuit and shunting the dry-cell current through the magneto winding (which path is of greater resistance), a kick voltage is set up in both the primary winding of the armature and the winding of the booster coil. The kick voltage of the booster coil, being set up in the same direction as that in the primary winding of the armature, helps to increase the inductive effect because of the increased condenser discharge, thereby inducing a higher voltage in the secondary winding. The same effect is produced during each half revolution of the armature on account of the rectifying effect of the two-segment commutator.

Caution!—From the above explanation, and a study of the circuit diagram of Fig. 299, it is evident that several things may occur to prevent proper ignition. For example, reversing the polarity of the dry cells, or reversing the polarity of the magnets (when installing on the magneto), will prevent ignition within the cylinders However, reversing both the dry-cell polarity and the magnets will neutralize the effect, and proper ignition will result, but the polarity marks on the breaker cover will be reversed. Another trouble often experienced is that the negative side of the dry cells becomes grounded, due to the zinc cans of the dry cells wearing through the paper cartons, thus making metallic contact

on the car frame. This will cause grounding of the magneto armature through half of each revolution and, in a four-cylinder engine, results in misfiring in two cylinders. On the other hand, in case a ground should occur between the starting switch and terminal No. 1 on the breaker, misfiring will result on the other two plugs. As soon as the engine starts, and the starting pedal is released, the dry cells are automatically disconnected by the opening of the contacts in the starting switch and the magneto operates as a simple high-tension magneto. The platinum breaker points should open 0.015 in.

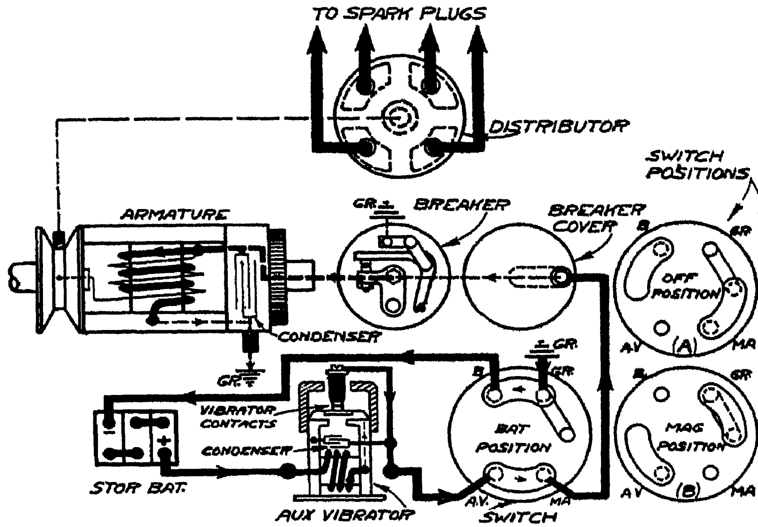


FIG. 300.—Circuit diagram of Bosch high-tension magneto with auxiliary vibrator.

180. The Bosch High-tension Magneto with Auxiliary Vibrator.—A circuit diagram of the Bosch high-tension magneto ignition system using an auxiliary vibrator coil is shown in Fig. 300. As may be seen the kick coil found in the Simms system, just described, is replaced by a small master vibrator or booster coil with a vibrator and with a condenser connected across the vibrating points. This auxiliary vibrator is mounted in an aluminum case, as shown in Fig. 301, usually located on the back of the dash or close to the magneto on the chassis frame. The vibrator, as will be seen from the diagram, is connected in the battery circuit and operates only when the switch is thrown to the "Battery" operating position.

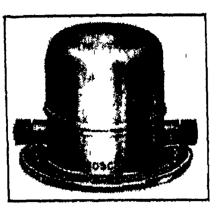


FIG. 301.—Bosch auxiliary vibrator, type VD.

The circuits shown are for the switch in the "battery" position. The two views to the right, (*a*) and (*b*), show the switch in the

"Off" and in the "Magneto" positions respectively. When the switch is on the "Battery" position, as shown, the battery current flows through the vibrator-coil circuit, through the switch, across the breaker points (which are normally closed), through the ground to the grounded terminal of the switch, and across the switch back to the negative side of the battery. During the period of breaker-point closure, the coil continues to vibrate, the vibrating points being protected by the condenser incorporated with it. At the moment the breaker points open, the battery current is directed through the primary winding of the armature (the vibrator continuing to vibrate as before), thus making and breaking the primary circuit at high speed. Since the vibrating points have a condenser connected across them, the unit will act like a master vibrator, causing the magneto armature to act as a vibrating-type induction coil and to deliver a shower of vibrating sparks to the plug.

It should be remembered that, at the moment the breaker points of the magneto armature open, the primary-armature current has reached its full value, so that, instead of being interrupted entirely by the opening of the breaker points, it is merely thrown into the vibrator-coil circuit. Thus, since no two-segment commutator is used in this system to convert the battery current into alternating current in the magneto winding (as in the Simms magneto), the battery voltage will have to oppose the magneto primary voltage during one-half of each revolution. This effect is not as great, however, as may be supposed, since, with the vibrator coil in circuit with the battery, the current cannot rise over a fixed amount which is dependent upon the tension of the vibrator, while in the non-vibrating coil used in the Simms booster-coil system the current can increase to its full value where, according to Ohm's law, $I = \frac{E}{R}$ With the vibrator in proper adjustment, this system will provide a shower of sparks at the plugs when starting on the battery, but the spark will be of greater intensity in alternate plugs to fire. With the switch in the "Magneto" position the battery is disconnected as well as is the magneto grounding wire. With the switch in the "Off" position the battery is disconnected, and the wire leading from the magneto-breaker terminal is grounded through the switch.

In systems of this type, care should be taken to employ batteries of proper voltage (usually not over 6 volts) and not to short-circuit the vibrator when the switch is on the "Battery" position. If the battery is permitted to discharge freely through the magneto winding, it is possible that the magnetizing effect of the battery current flowing through the primary winding of the armature will be sufficient to demagnetize the magneto magnets to some extent. With the vibrator properly adjusted—that is,

to a maximum current flow of, say, 2 amp. on a 6-volt battery—no trouble will be experienced in the demagnetizing of the magnets, nor will the opposition offered by the battery current be sufficient to prevent ignition during the opposed half of the armature revolution.

The timing and adjusting of the magneto itself is the same as for any of the regular Bosch magnetos.

181. The High-tension Dual Magneto.—As previously stated, the purpose of the high-tension dual magneto is to employ battery current for starting, thereby producing a better spark at low engine speeds. In the high-tension dual magneto, a separate breaker is provided for the battery current, usually located in the same housing with the regular magneto breaker, but timed to open 10 deg. later than the magneto breaker. The object of this difference in timing is to automatically retard the timing of the spark by throwing the switch from the "Magneto" to the "Battery" position. This avoids the danger of the engine kicking back in case the operator should attempt to crank by hand without first retarding the spark-control lever.

In the high-tension dual-magneto system, the winding of the magneto armature is entirely inoperative when the system is running on the battery, the high-tension current being induced in a separate induction coil usually incorporated in the switch housing. The only part of the magneto which functions when the system is operating on the battery is the battery breaker and the high-tension distributor for directing the high-tension current to the various spark plugs in their proper order of firing. To make this possible, however, it is necessary to disconnect the high-tension circuit of the magneto from the center point of the distributor by a switch.

A high-tension dual-magneto system may be readily recognized because the high-tension collector-ring brush terminal does not connect directly to the center of the distributor, as in the plain high-tension-type magneto. Instead, the collector ring is connected to the distributor by two high-tension-type cables leading to the switch, which connects the two only when on "Magneto" operating position. Thus, five high-tension terminals are necessary on the distributor head for a four-cylinder magneto, and seven terminals for a six-cylinder magneto. With the exception of the extra battery breaker and the extra high-tension terminal on the distributor head, most high-tension dual magnetos are identical with those of the standard types.

182. The Bosch High-tension Dual Magneto.—The Bosch high-tension dual magneto with the breaker cover removed is shown in Fig. 302. As will be noted, the magneto breaker is of

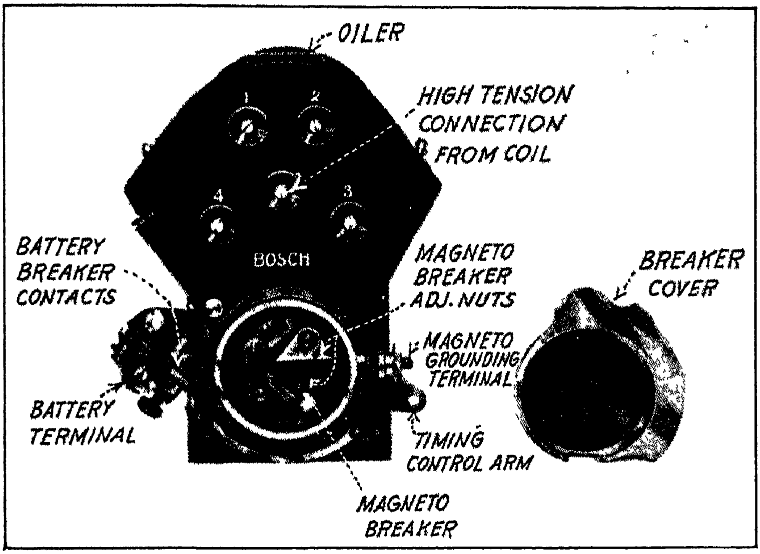


FIG. 302.—The Bosch high-tension dual magneto showing breakers.

the standard Bosch construction, being mounted on a plate rotating as a unit with the armature and operated by steel cams on the inside of the breaker housing. It will also be noted that the

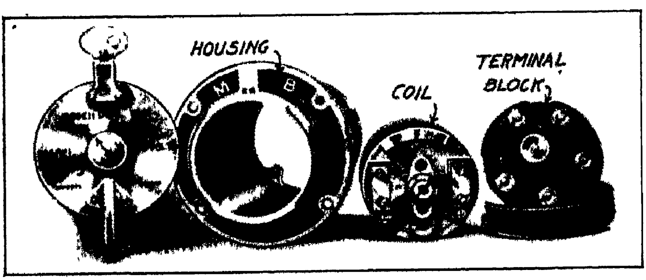


FIG. 303.—Parts of Bosch dual coil.

battery breaker is located at the left of the magneto breaker, and is actuated by two cam lobes on the periphery of a disc at the back of the magneto breaker which rotates with it.

The switch unit is so designed that the coil and the switch lever rotate as a unit in the housing, the coil connections being

made by inlaid segments in a fiber block mounted on the end of the coil. These segments register with the stationary switch contacts in the rear of the coil housing. The switch has three positions "Magneto," "Off," and "Battery," the latter position being as shown in the diagram. A sectional view of the coil and switch unit is shown in Fig. 303. A circuit diagram of the system is shown in Fig. 304.

The coil, as will be seen, contains a vibrator with a push button so arranged as to cut the vibrator into or out of the coil circuit. Normally this vibrator is out of circuit, but the turning of the button places it in the battery primary circuit in case the vibrator

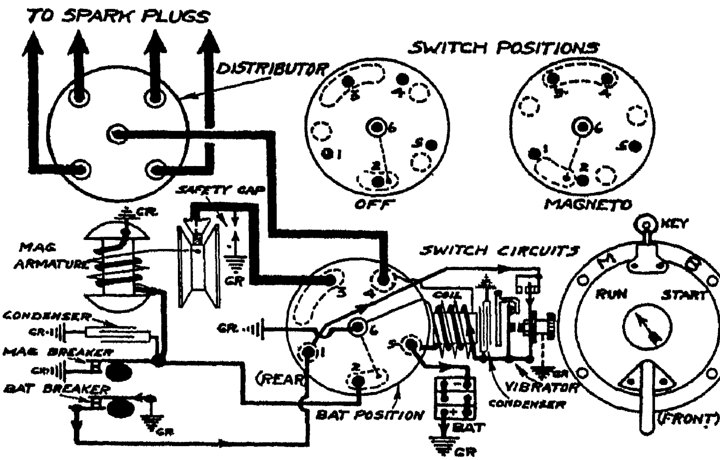


FIG. 304.—Circuit diagram of Bosch high-tension dual-magneto ignition system.

spark is desired for starting purposes. With the switch on "Battery" position, the segments on the rear end of the coil line up with the coil-terminal contacts in such a way that the magneto-breaker grounding wire is directly connected to the ground, thus preventing a high-voltage current from being produced in the armature. The switch also disconnects the high-tension armature collector ring from the distributor and, instead, connects the high-tension winding of the induction coil with it.

By a study of the circuits, it will be found that the battery current flows as follows: From the positive terminal of the battery through the ground to the grounded side of the battery breaker, across the breaker, returning to terminal No. 1 on the coil, across the upper vibrator contacts which are normally closed, through the primary winding of the coil, and out

through terminal No. 5, and back to the negative side of the battery. The high-tension circuit is from terminal No. 4, which connects with one end of the high-tension winding of the coil, to the center terminal of the distributor, thence to the spark plugs, returning through the ground and grounded terminal No. 6 on the coil. In case the push button on the coil should be turned to the right, or "Start," position, the vibrator is released so that it is free to vibrate when battery current passes through it, thus setting up a vibrating spark at the plug. A condenser is also incorporated in the coil and is connected across the vibrator points so as to protect them from pitting and so as to produce a higher voltage in the secondary winding

In the "Off" position of the switch the magneto armature is still grounded, and the battery is disconnected from the circuit, so that no spark can be produced

In the "Magneto" position of the switch the magneto-breaker grounding wire is disconnected from the ground, thus allowing the magneto to operate while the battery is entirely disconnected from the circuit. In this position of the switch, terminals Nos. 3 and 4 on the coil are connected by a segment in the switch, thus completing the high-tension circuit from the collector ring on the armature directly to the center terminal of the distributor. Normally, when operating on the battery, the push button should be turned to the left, or "Run," position, in which case a single spark is produced each time the battery breaker points open.

Note —In case of an emergency, such as a defective switch unit, the high-tension dual magneto may be operated as a simple high-tension magneto by running a high-tension wire from the collector-ring terminal to the center of the distributor. It is evident, however, that the usual high-tension magneto cannot be used as a dual magneto without changing the distributor and breaker mechanism

183. The Eisemann High-tension Dual Magneto Ignition System.—The Eisemann high-tension dual magneto, known as type GR4—II Edition, is shown in Fig. 305. It is used in conjunction with a battery (either dry cells or storage battery) and either the DC or the DCR coil shown in Fig. 306.

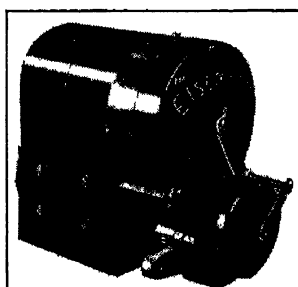


FIG. 305.—Eisemann dual magneto, type GR4—II Edition

The primary purpose of this system is to give two sources of ignition (magneto and battery), using one set of spark plugs. The arrangement consist esssentially of a direct high-tension magneto, used in conjunction with a combined transformer coil and switch which can be mounted on the dash. This transformer coil is used only in connection with the battery, whereas the switch is used in common with both the battery and the magneto.

The magneto, as may be seen from Fig. 305, is practically the same as the type G4 independent magneto, with two exceptions: The timing arm is equipped with an extra separate contact breaker for the battery current, and the distributor is modified

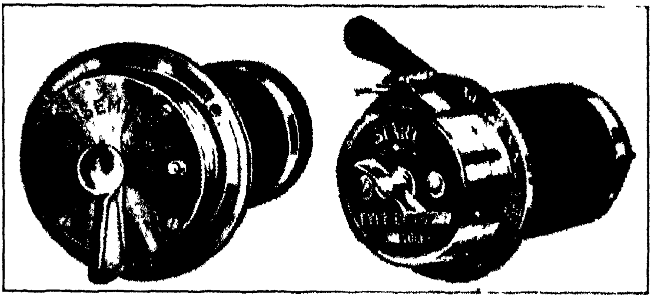


FIG. 306.—Coils used with Eisemann dual magneto.

to permit of its electrical separation from the magneto armature when distributing the battery high-tension current.

This magneto may be used with equally good results with either of the Eisemann dash coils, type DC or type DCR, Fig. 306.

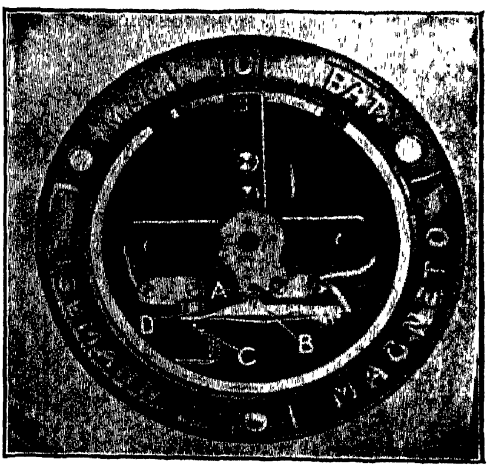


FIG. 307.—Eisemann type DCR coil with front plate removed showing mechanism for starting on the spark.

The coils differ only in the arrangement for starting on the spark, the type DC having a push button giving a single spark, provided the engine happens to stand with the battery breaker open,

while the DCR has a mechanical ratchet device, delivering a shower of sparks regardless of the crank position of the engine.

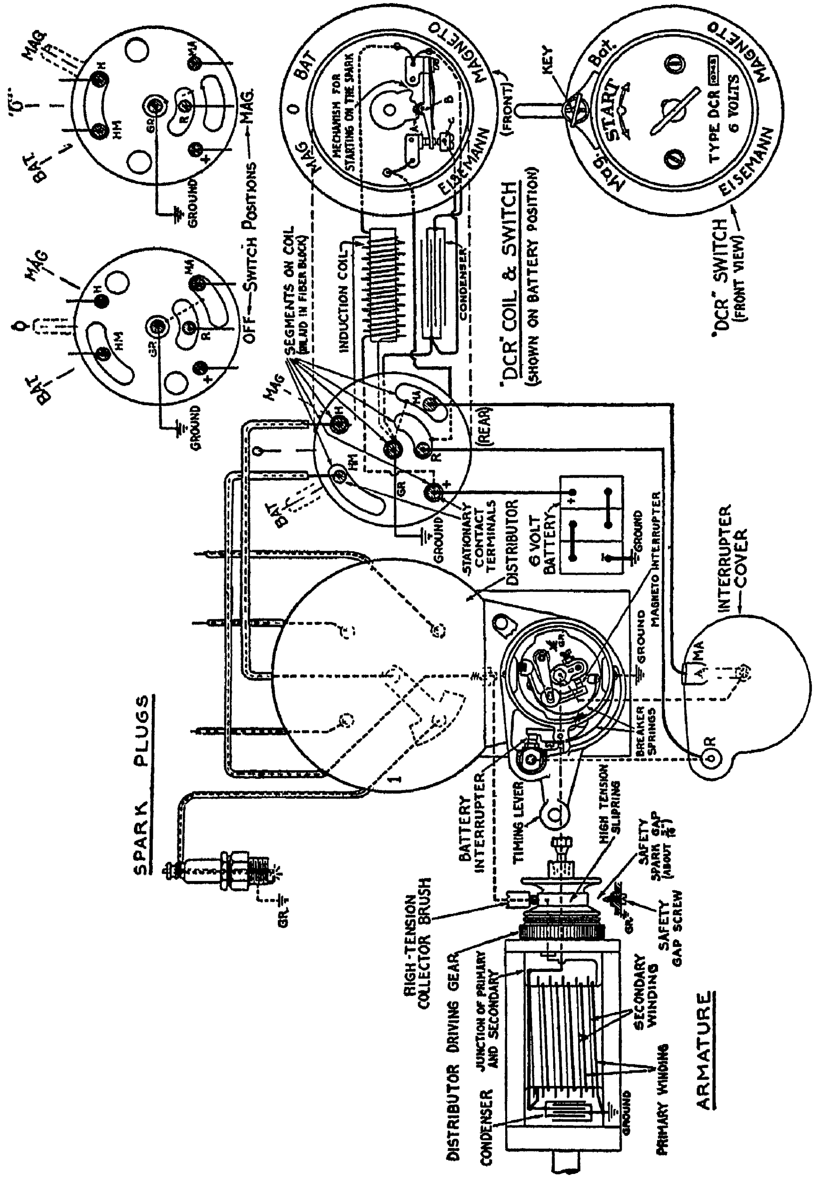


FIG. 308.—Circuit diagram of Eisemann high-tension dual magneto, type GR4, with type DCR coil.

A rapid back-and-forth motion of the starting handle on the front of the DCR coil causes the toothed ratchet in the center to

oscillate the lever *B*, Fig. 307, which in turn, makes contact alternately at *C* and at *D*. If the switch is on "Battery" position and the battery breaker points in the magneto are closed, as they normally are, a rapid sequence of sparks will occur at the plugs. This shower of sparks is much more effective for starting on compression than is a single spark.

A circuit diagram of the system, including the coil connections for the different switch positions, is shown in Fig. 308. The battery breaker operates in much the same manner as the interrupter on the magneto. It is actuated mechanically by two polished steel cams attached to the magneto breaker, but is entirely separate, electrically, from it. Like the magneto breaker, the battery causes the spark to occur at the instant of separation of the contact points. For practical reasons, as previously explained (Art. 181), this interruption is timed to take place 10 deg. later than the magneto, but is subject to the same degree of advance and retard, as it is mounted in the same timing-lever body. Both breakers are protected by the same water-proof cap and are easily exposed to view.

Both sets of contact points should be adjusted to open from 0.012 to 0 014 in. The distributor is the same as the G4, except that there is no connection between the lower carbon (collector) brush and the center one. Cables lead from each of these brushes to the switch portion of the coil, permitting the center brush to be connected to the lower one when running on the magneto, or to the coil when running on the battery.

If for any reason it is desired to operate the magneto without the coil and switch unit, it may be operated as an independent high-tension magneto, the same as the type G4, by connecting the cables marked *H* and *HM* on the distributor head, thus making a direct path for the high-tension current from the collector ring to the center distributor brush.

184. The Impulse Starter.—One serious objection to magneto ignition is the complication introduced by the added battery or dual equipment for obtaining better sparks when the engine is being started. As previously outlined, the ordinary magneto does not usually give a spark of sufficient intensity at cranking speeds to fire the gas in the cylinder—particularly when cold. This drawback has been overcome to a large extent by installing on the drive end of the magneto armature a mechanical device known as an *impulse-starter* coupling. This consists of a mechanical spring-operated device which is arranged to throw the magneto armature, or rotor, at high speed for approximately half a revolution, thus producing a higher voltage and a better spark.

The general scheme employed in the impulse-starter coupling is to lock the armature from rotating for a short period of rotation

during which period the spring in the impulse starter is being compressed; then to release the armature suddenly by the tripping of a latch or *trigger*. The energy stored up in the compressed spring is sufficient to give the armature a rotative speed equivalent to 500 to 600 r.p.m. for approximately a 180-deg. rotation.

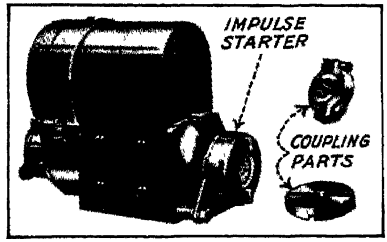


FIG 309.—Application of impulse starter to Eisemann magneto

Figure 309 shows the application of the impulse starter on the Eisemann magneto, while a diagrammatic sketch of it is shown in Fig. 310. Figure 310*B* shows it with the spring in the extended position, while Fig. 310*C* shows it with the trigger caught in the notch and the spring compressed. This device, which may be attached to any model of the Eisemann magneto, has no effect

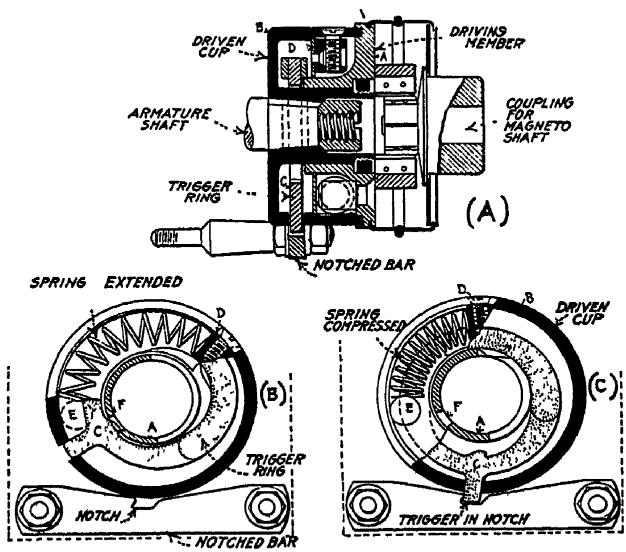


FIG. 310.—Diagrammatic sketch of Eisemann impulse starter (*A*) Sectional view. (*B*) Showing spring extended. (*C*) Showing spring compressed.

on the operation of the magneto at ordinary running speeds. At low engine speeds, however, it causes the armature of the magneto to rotate in a series of jumps instead of uniformly. These jumps cause the armature to cut the lines of force from the

magnets at the same speed as when the engine is turning over rapidly, so that a hot spark is generated at both speeds.

As may be seen from Fig. 310, the starter consists of a driving tube *a* and a driven tube or cup *b*, the cup being connected by a spring. Within the driven cup is a loose ring *c*, called the trigger. This ring has a projection, which extends through a slot in the outer surface of the cup. Below the device is a notched bar bolted to the end housing of the magneto and so placed that, as the cup revolves, the notch registers with the slot in the cup so that the trigger lip drops down by gravity, catches in the notch, and locks the cup against rotation. This is the condition shown in Fig. 310*C*. When the lip is engaged in the notch bar, and the cup stops revolving, the driving tube continues to turn. This compresses the spring against a driving pin on the tube and a block fixed to the cup. At the proper point, the cam on the trigger ring engages that on the tube and lifts the trigger out of the notch in the bar. The compressed spring then spins the armature of the magneto past the firing point and provides a hot spark. At cranking speeds the trigger is caught again and again as it passes the notch, but, when the engine fires, the speed immediately increases to the point where the trigger ring is prevented from entering the notch by centrifugal force. At this speed the coupling acts as a solid connection between the drive-shaft and the armature.

The principles involved in the other makes of impulse starters are practically the same as for the one described; however, the details of the construction may vary a great deal. The only disadvantage found in the impulse starter is that through constant usage the spring may break, or the latch mechanism become worn or broken, thus requiring replacement. However, these parts are not expensive and can be replaced readily. The impulse starter will be found a great advantage on heavy-duty truck and tractor engines which are usually hard to crank.

185. Motor-cycle Ignition.—The ignition for motor-cycle engines may be supplied either by a battery system or a high-tension magneto, the latter being in more general use. Since the most widely used motor cycles are of the two-cylinder V type, however, problems arise, particularly in magneto ignition, in providing sparks of equal quality in both cylinders and at the proper time.

It should be remembered that the angles passed through by the crankshaft between explosions in a two-cylinder V-type engine are unequal, the angles being 402 and 318 deg. for a

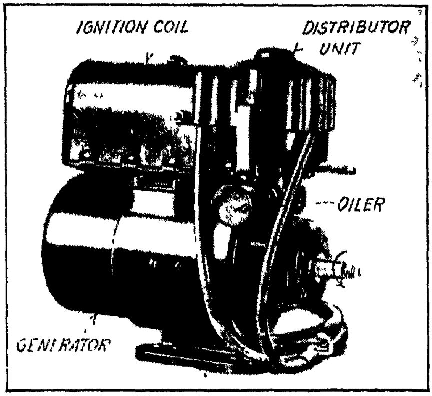


FIG. 311.—Remy generator and ignition unit for Harley-Davidson motor-cycle.

42-deg. engine, 405 and 315 deg. for a 45-deg. engine, and 410 and 310 deg. for a 50-deg. engine. Examples of motor-cycle engines

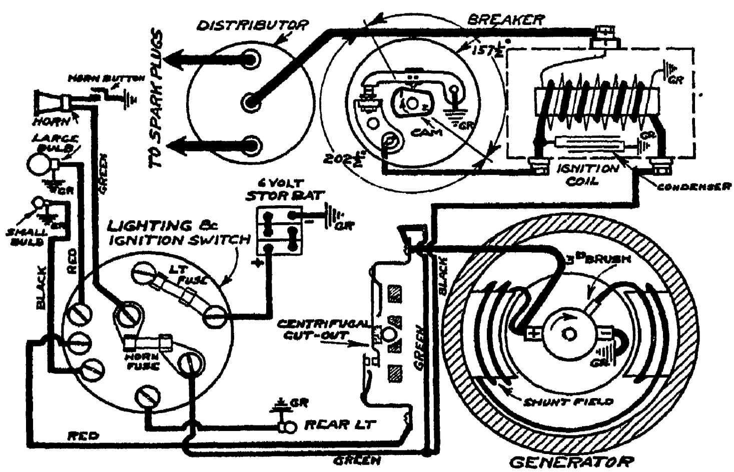


FIG 312.—Circuit diagram of Remy battery ignition system on Harley-Davidson motor-cycle, model 18-J.

with these angles are the Indian, Harley-Davidson, and Excelsior, respectively.

186. Remy Battery Ignition System for Harley-Davidson Motor Cycle.—The Remy battery ignition system as furnished on a large

number of Harley-Davidson motor cycles consists principally of a 6-volt generator, on one end of which is mounted the breaker and distributor unit, Fig. 311; a 6-volt storage battery; a lighting and ignition switch; lamps; and all necessary wiring. A circuit diagram of the system as installed on the Model 18-J is shown in Fig. 312.

As will be noted, the breaker cam has one large and one small lobe, in order to provide sparks at the unequal angles of 405 and 315 deg. required by the engine, which is of the two-cylinder V type with cylinders set at an angle of 45 deg. The breaker shaft is driven through spiral gears from one end of the generator armature at one-half crankshaft speed. Thus, the angles included between the lobe corners Nos. 1 and 2 (which cause the opening of the breaker points) must be one-half of the crank angles of 405 and 315 deg. or 202½ and 157½ deg. respectively. The leading corner of the large lobe (indicated in the diagram as No. 1) should be timed to provide ignition in the rear cylinder, while the leading corner of the small cam lobe provides ignition in the front cylinder, since the crank moves through the larger angle of 405 deg. from the time the rear, or No. 1, cylinder fires until the front, or No. 2, cylinder fires. It is then followed by the smaller angle of 315 deg. from the time the front, or No. 2, cylinder fires until the rear, or No. 1, cylinder fires again. It is evident from the above that, if the ignition should be timed with the wrong cam lobe, for example, the rear cylinder timed with the No. 2 cam lobe, the front cylinder would fire 405 minus 315 deg., or 90 deg. too early, which might prevent the running of the engine. On the other hand, if the front cylinder should be timed with cam lobe No. 1, the rear cylinder will fire 90 deg. late, the result being either a very feeble explosion in the cylinder, or misfiring entirely, followed by popping in the exhaust valve.

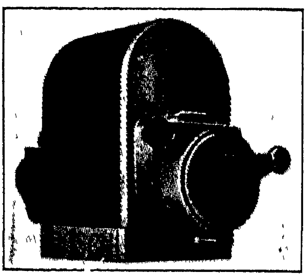


FIG. 313.—Bosch magneto type ZEV, for 2-cyclinder V-type motor-cycle ignition.

187. The Bosch Magneto, Type ZEV, for Two-cylinder V-type Motor-cycle Engine.—The Bosch magneto, type ZEV, which has been used very widely on V-type motor-cycle engines, is shown in Fig. 313. This magneto can be furnished for 42-, 45-, or 50-deg. arrangement of the cylinders. The circuit diagram of this magneto for a two-cylinder V-type engine is shown in Fig. 314. As may be seen, the cams for operating the breaker are not located diametrically opposite, but at unequal angles, to provide sparks at the unequal angles required by the engine, for example, 405 and 315 deg. apart in the case of a 45-

deg. type engine. The magneto armature rotates at one-half engine speed; thus the angles between cams are 202½ and 157½ deg. for a 45-deg. engine. For a 42-deg. engine these angles are

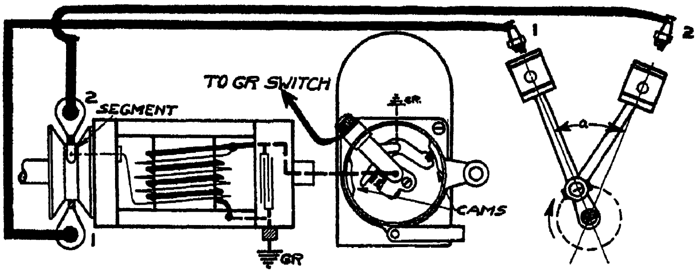


FIG 314 —Circuit diagram for Bosch magneto, type ZEV

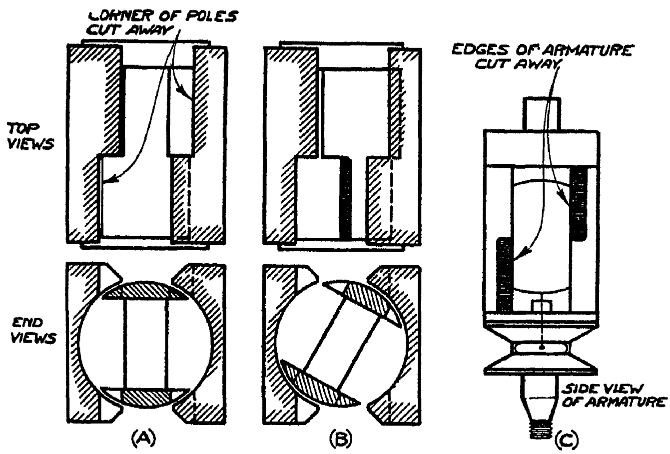


FIG. 315 —Pole construction used in two-cylinder, V-type, magnetos. (*A*) Position of armature when breaker opens on full advance with spark in No 1 cylinder (*B*) Position of armature when breaker opens on full advance with spark in No. 2 cylinder (*C*) Side view of armature showing edges of core cut-away.

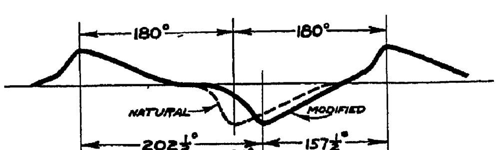


FIG 316.—Current wave from two-cylinder 45-deg. magneto.

201 and 159 deg., and for a 50-deg. engine 205 and 155 deg. respectively. In order to produce equally good sparks at these unequal angles, the pole pieces are specially cut away, as shown

in Fig. 315. By varying the point of magnetic break in this manner, the current wave from the armature will be modified to that shown in Fig. 316. It is evident that changing the primary current wave in this manner enables the breaker to still open when the current is at its highest value during each half revolution, thus not diminishing the quality of the spark in one of the cylinders, as would be the case with standard pole construction.

The distributor in this type of magneto takes the form of a high-tension slip ring, as shown in Fig. 314, in which the metal segment extends only part way around. Thus, during one-half revolution of the armature it connects the high-tension winding to one plug, and during the other half revolution, to the other plug. In other respects the magneto corresponds to standard Bosch construction and operation. The breaker points should be adjusted to open 0.015 to 0.017 in.

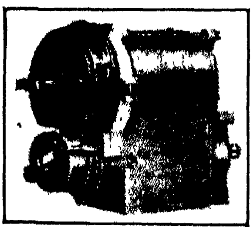


FIG. 317—Simms aviation magneto, type L-8.

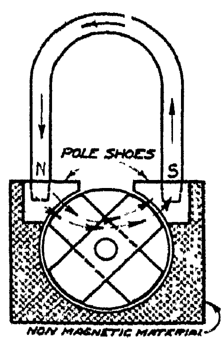


FIG. 318.—Diagrammatic end view of Simms, type L-8, magneto

188. The Simms Aviation Magneto, Type L-8.—The Simms aviation magneto, type L-8, Fig. 317, has been widely used for aircraft ignition on eight-cylinder engines set at 90 deg. It departs from the usual high-tension magneto construction in that the magnets are in the form of round rods, four in number, instead of the usual flat-bar construction. These magnets are ground to a taper at their poles and the pole pieces are bored and reamed to a corresponding taper, so that the magnets, when forced into these tapering holes, make excellent contact with the pole pieces, thereby insuring a very good magnetic circuit.

A diagrammatic end view of this magneto is shown in Fig. 318, while a circuit diagram is given in Fig. 319. The poles are arranged on the quarter. A four-lobed rotor, similar to that in

the K-W high-tension magneto, is used. However, it differs from the K-W in that the winding, which is mounted between the lobes, rotates with the rotor and the shaft as a unit instead of remaining stationary. It is necessary, therefore, in this magneto to provide a rotating type of breaker and a slip ring for collecting the high-tension current. Thus, the magneto may be classed as a straight armature-type machine but having the K-W-type instead of the H-type rotor. The armature develops four pulses of current per revolution; therefore, it is suitable for four- or eight-cylinder engine ignition and may be run at one-half the speed of the ordinary bipolar machine, in order to give the same number of sparks.

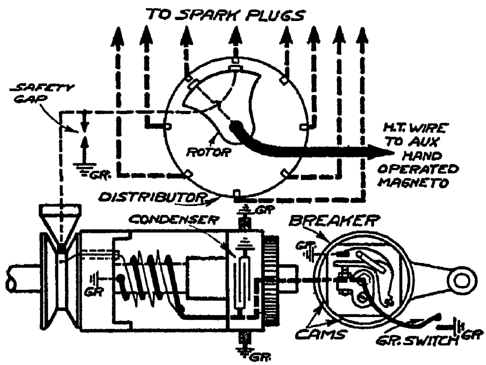


FIG 319—Circuit diagram of Simms magneto, type L-8.

Simms Distributor of Special Type—Application of Hand-operated Magneto.—In some airplanes it is preferable to be able to start the motor by turning over the propeller blades. Some engines are provided with a fixed spark advance, that is, the spark is set permanently to occur at so many degrees ahead of top dead center, while others are provided with spark advance and retard.

In order to start an engine having spark advance, an extra hand-operated magneto is often provided which, when rotated, will develop a train of sparks similar to that delivered by a vibrator coil. The high-tension terminal of this magneto is connected to the special distributor terminal at the center of the distributor rotor in a manner similar to that used in either the low-tension dual-magneto systems or in high-tension dual systems. However, this terminal does not connect to the distributor arm, which distributes the high-tension current to the various plugs in the usual way, but, instead, connects to a separate arm, insulated from it, and provided for this purpose. Thus, there are two distributing segments insulated from each other, one connecting to the high-tension slip ring of the magneto, the other

to the high-tension terminal of the hand-operated magneto. The two arms do not make contact with the distributor spark-plug wire connections at the same points, but are arranged so that the hand-operated magneto is always connected to the cylinder that has just passed its firing point.

When the engine is to be started, the ignition system is cut off entirely and the engine is cranked over a number of times, so that the cylinders are primed with burnable charges. The pilot then assumes his position in the airplane and, when ready to start, turns on the ignition switches and cranks the small hand-operated magneto rapidly, thus delivering a shower of sparks in the cylinder. The sparks occur in the cylinder, which is charged with a burnable gas, and the piston of which has passed top dead center some distance in the direction of normal rotation. This shower of sparks is to set off the charge of gas in the late cylinder, creating sufficient explosive force to kick the engine over at a sufficient speed to produce good ignition from the regular magneto. The pilot should then advance the spark to suit the engine speed and the hand-operated magneto remains inoperative until the next time it is needed for starting.

This scheme of starting avoids the danger of the propeller kicking back, thus injuring the operator in case he should attempt to crank the engine with the spark lever left in an advanced position—either permanently or accidentally.

SECTION XII

IGNITION EQUIPMENT TROUBLES AND ADJUSTMENTS

189. Faulty Ignition.—Faulty ignition is indicated by failure of the engine to start, or by misfiring—"missing" of the engine while running. Misfiring may be caused by faulty carburetion, improper valve action, loss of compression, or excessive lubrication. It is important, therefore, that the repairman be able to distinguish between ignition troubles and other troubles which result in an apparent faulty operation of the ignition system.

190. Locating a Misfiring Cylinder.—To detect and correct faulty ignition, the cylinder at fault must first be located. This may be easily done, with the engine running, by short-circuiting the spark plug, that is, bridging between the engine cylinder and the spark-plug terminal with either a hammer head or a wooden-handled screwdriver, as shown in Fig. 320. If, in testing the various spark plugs, one is found which, when short-circuited, does not affect the operation of the engine, it is in all probability the one at fault. The trouble may be either in the ignition apparatus or in the spark plug.

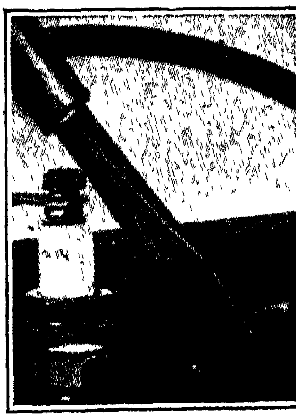


FIG. 320.—Method of short-circuiting spark plug in locating misfiring cylinder.

Another convenient method of locating a misfiring cylinder on engines having vibrating-coil ignition, such as the Ford, is to run the engine first on one cylinder and then on another by holding down all the vibrators except the one connected to the cylinder under test. The engine should run idle on any one of the cylinders and should show approximately the same power from each.

191. Defective Spark Plugs.—a spark plug may be defective on account of one or more of the following reasons:

1. Carbonized.
2. Improper spark-gap setting.
3. Cracked porcelain.
4. Improper installation.
5. Improper design.
6. Defective construction.

These conditions may be determined and remedied as follows:

1. *Carbonizing or sooting*, which is the most common cause of spark-plug failure, is caused by improper carburetion, over-lubrication or both. The carbon or the oil deposited on the porcelain of the plug causes a partial or a complete short-circuiting of the high-tension current, so that, instead of a hot spark jumping between the spark-plug points, the high-tension current passes through the carbon or oil accumulation, causing a misfire, especially under conditions of wide-open throttle and heavy compression.

A carbonized or sooted spark plug may be cleaned of all carbon by washing it with gasoline and a stiff brush.

Poor carburetion and over-lubrication of the engine should also be corrected if possible. In some cases excessive lubrication or "oil pumping" in the cylinder is hard to overcome. It is, consequently, difficult to obtain good ignition until the cause is remedied. In some instances an auxiliary spark gap (spark intensifier) in series with the plug may be found helpful. Again, it may require a special third-point or "ionizing" type of spark plug (such as the Radd) to fire the fuel charge. This type of plug fires at lower voltage and is not shorted as readily by oil or carbon as the ordinary type of plug.

Note.—In cleaning the porcelain of a plug, a sharp-edged metallic tool should not be used to remove the carbon, as the scraping is liable to leave metallic marks on the surface which may short-circuit the plug even more than the carbon. Emery cloth should never be used, as it will remove the glaze and roughen the surface of the porcelain, causing carbon to deposit more readily. If the carbon deposit is due to a cracked, roughened, or porous porcelain, the only remedy is to replace either the porcelain or the plug. Cleaning the outside of a porous or roughened insulator will not clean out the carbon deposits deep in the pores.

2. *Improper Spark-gap Setting.*—The proper distance between the spark-plug points depends upon the compression pressure of the engine, since the resistance across the gap rises in proportion to the compression. Ordinarily, the gap should be between 0.025 and 0.030 in., or the thickness of three standard U. S. post cards, which may be used as a gage. The lower the compression pressure, the wider the points can be set without causing misfiring. If the gap is found incorrect, the electrode attached to the shell may be bent until proper adjustment is secured. Too wide a gap will usually cause an engine to misfire on heavy pull, while too small a gap will usually cause the engine to miss due to short-circuiting of the points, or because a spark of sufficient length and heat to ignite the gases is not provided between the electrodes.

Because of the action of the spark, the sparking points will gradually wear away, causing a widening of the gap. If the points tend to wear too

rapidly, the reason may be either poor material or faulty construction of the electrodes. Rapid wearing of the points will also result if the electrode wires are too small, particularly in magneto ignition. To avoid rapid wearing, the points should be made of a good heat- and oxygen-resisting metal, such as tungsten, nichrome, nickel steel, or pure nickel. Common iron, brass, copper, or steel points should not be used.

3. *Cracked Porcelain.*—A cracked porcelain usually results in the high-tension current bridging the gap between the center electrode and the shell through the crack in the porcelain instead of jumping across the plug points. This is true especially under heavy compression. The porcelain may be cracked in such a manner that it will not show upon casual inspection. In this case it may be detected as follows: If the plug is screwed into the cylinder and some pressure is brought to bear against the upper end of the plug with the finger, a grating or grinding sound will sometimes be heard and a small movement felt. In such cases it may be necessary to take the plug apart to determine if the porcelain is cracked or broken. The only remedy for a cracked porcelain is to substitute either a new porcelain or a new plug.

A cracked porcelain may be caused by: (*a*) tightening the gland nut too tight when the plug is cold, resulting in cracking when the plug heats up; (*b*) sudden excessive heat from the engine, causing the porcelain to crack on account of the sudden change in the temperature and bearing pressure at the point where the gland nut and gasket hold the plug shoulder to the shell; (*c*) excessive internal gas pressure due to preignition; (*d*) striking of plug with a metallic tool; (*e*) applying wrench to gland nut by mistake when screwing the plug into cylinder; and (*f*) poor-quality porcelain.

4. *Improper Installation*—The method of installing spark plugs in the cylinder head should usually be such that the inner edge of the shell is flush with the inner surface of the cylinder head wall; that is, the electrodes should be the only part of the plug to extend into the combustion chamber. If the plug is too long and the shell extends into the combustion chamber, the protruding portion may become over-heated and cause preignition.

On the other hand, if the plug is not of sufficient length, a dead space or pocket is formed for the gases, resulting many times in fouling and misfiring of the plug. Correct and incorrect plug installations are shown in Fig. 106.

5. *Improper Design*—The design of the plug, especially the sparking electrodes, has much to do with the spark-plug performance in different types of engines and with different ignition equipment.

To give the best ignition spark, regardless of polarity, both electrodes should be of the same size, shape, quality of material, and arranged in the same way.

6. *Defective Construction.*—The spark plug may be at fault, due to poor material or workmanship entering into its manufacture and assembly. The porcelain may be either of poor quality or insufficiently glazed, causing current leakage either through the porcelain at high temperatures and pressures or over the surface, due to the carbon accumulation in the pores. It is important also that the porcelain be clamped tightly against its seat

in the shell with a gasket of sheet copper and asbestos between to insure a perfect fit between the insulator and the shell to prevent gas leakage.

In the case of mica plugs, the mica should be so arranged, and held under sufficient pressure, that the layers of mica cannot spread so as to permit oil or carbon to work between them.

A positive test for any plug is to replace it with one that is known to be perfect and of good quality. If the engine operation is thereby improved, the original plug is unquestionably at fault.

192. Defective High-tension Wiring.—If the spark plugs are found in good order, and the cylinders have proper compression, and yet one or more cylinders continue to misfire, the trouble may be due to a leak of secondary voltage and current in the wire connected to the plug. The trouble can be located when the engine is running, or being cranked, by detaching the wire from the plug and holding the end 1/8 to 1/4 in. from the plug-binding terminal or the cylinder head. If the secondary current is being distributed properly to the cylinder in question, a spark will occur at the gap. If there is no spark across the gap and there is regular sparking at the other plugs, the trouble is undoubtedly due to defective high-tension wiring, a cracked distributor head, or poor timer contact.

If the rubber covering or insulation on the spark-plug wires is chafed or cut through, allowing the conductor to touch or nearly touch any metal part of the car, the high-voltage current will be short-circuited and will not jump the gap in the plugs. It is not necessary that this insulation be worn down to the metal of the conductor in order to cause a short-circuiting of the secondary current. If a sharp snapping sound is heard, particularly when the engine is running under a heavy pull, it is evidence of a short circuit from the high-tension conductor to the metal of the engine or car.

Testing the High-tension Wiring.—Since the high-tension insulation must withstand approximately 10,000 volts, or over, in actual service, it should be tested at approximately this voltage. The test may be made with two secondary leads from a spark coil as shown in Fig. 321. This shows a standard Ford induction coil with a safety gap of 3/8 to 1/2 in. provided. When the switch is turned on, the high-tension spark will operate across the safety gap until it has an easier path between the two test points.

To test the insulation of a high-tension wire, hold one test point to the metal of the wire and explore the length of the wire with the other point. In case the insulation is defective, the spark will jump through the insulation

at the point of defect instead of across the safety gap. The only satisfactory remedy for defective high-tension insulation is to replace the wiring with new.

When new high-tension wiring is being installed, it is advisable to run the wires at least 1 in. apart; and they should be as nearly the same length as possible. The wires should also be supported so that the insulation does not come in contact with the metallic ground, particularly the heated parts of the engine, for example, the exhaust manifold, as the heat will cause the insulation to harden and crack

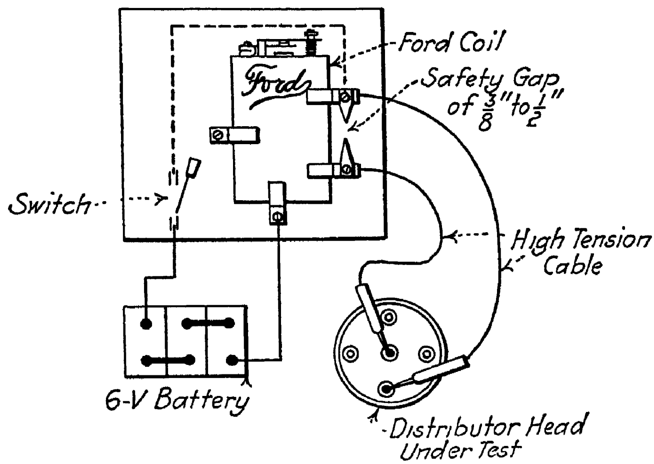


FIG 321 Method of testing high voltage insulation using Ford induction coil

193. Distributor Troubles.—High-tension distributor heads and rotors are usually made of a specially molded insulation known as Bakelite or Condensite, with the metal terminals or segments molded in position. Two principal types of construction are used: namely, the *gap* type and the *rubbing-contact* type. Troubles may arise, caused by:

1. Cracked or punctured insulation.
2. Accumulation of carbon or metallic deposit on rubbing surface, due to wearing of rotor brush or button.
3. Excessive wearing or cutting of rubbing surface.
4. Corroded segments.

To test a distributor for cracked or punctured insulation, test between terminal segments of distributor head with high-tension voltage (10,000 to 20,000 volts), using the method shown in Fig. 321. With current leakage through cracked or punctured insulation, the spark will jump through the insulation instead of across the safety gap. The distributor rotor or arm insulation should be tested in a similar manner with one test point on the

rotor segment and the other either inserted in the hole which fits over the timer shaft, in case the rotor is removed, or in contact with the metal work or ground, if the rotor is tested in position with the distributor head removed. In case a crack or puncture is found, the only remedy is a new distributor head or rotor.

Care of Distributor.—The rubbing-contact type of distributor should be inspected every 1,000 miles of service. Any carbon or metallic dust accumulation should be cleaned out. The rotor-brush track may be wiped clean by using a cloth moistened with gasoline or a little vaseline. The inside of the distributor should be wiped dry before it is put into service. If corroded, the segments may be polished either with brass polish or the rubber eraser on the end of a pencil.

In the gap-type distributor, no special attention is needed other than to make sure that the interior is well ventilated by small holes or openings properly placed so as to exclude dust and moisture. The ventilation will prevent the formation of nitric acid caused by the action of the spark in combination with the insulating material of the distributor head. The acid, so formed, would cause corroding of the terminals. The top of the distributor should be kept clean and dry.

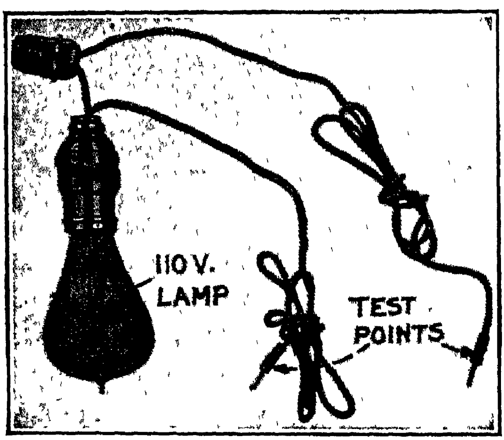


FIG. 322.—110-volt test lamp.

194. Defective Primary Insulation.—The kick voltage in the primary ignition circuit often reaches 200 volts upon the opening of the breaker points. Therefore, the insulated breaker terminals and the entire wiring of the low-tension system must be able to withstand this voltage, or even more; otherwise, considerable leakage may occur and cause poor action of the coil, and feeble ignition. One side of the low-tension system is usually grounded;

therefore, special care should be taken to prevent the kick voltage leaking to the ground.

Test.—To test the primary insulation for leakage, use a 110- or 220-volt (A.C. or D.C.) test lamp, Fig. 322 (preferably 220 volts), testing between the insulated terminal and the ground. In case of leakage through the insulation, the lamp will burn. If the tests are made using 110 volts, any leakage not sufficient to cause the lamp to glow may be detected by touching the ends of the test wires to the tongue, as shown in Fig. 323, when a tingling sensation will be felt. The leakage may be due to moisture or

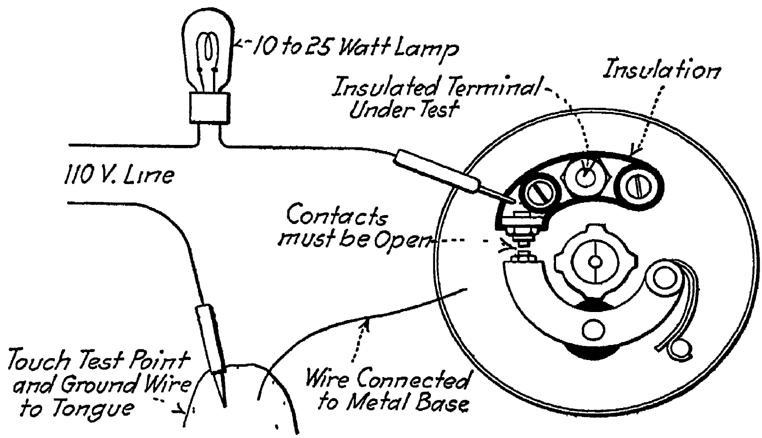


FIG 323.—Method of testing primary insulation in battery breaker for leakage

oil-soaked insulation, which can be remedied by cleaning and drying thoroughly.

Caution!—The test shown in Fig 323 should not be attempted unless the operator is standing on dry wood or cement or is otherwise insulated from the earth, as one side of the 110-volt test line may be grounded, thus endangering the operator. A suitable voltmeter can be substituted for the tongue in this test

195. Testing the Battery Ignition System.—If the engine is equipped with battery ignition, the system may be tested for the production of suitable sparks, as follows: The high-tension wire leading from the induction coil to the distributor should be disconnected at the coil. Then bring the end of a wire (the other end of which is grounded to the frame) to within ¼ in. of the secondary terminal of the coil. As the engine is cranked or the breaker points closed and opened with the switch "On," the quality of spark appearing at this gap can be noted. If a good snappy hot spark jumps between the secondary terminal and the

end of the grounded wire each time the breaker points are opened, it is evident that the various parts of the system, such as *coil, breaker, condenser, primary wiring*, etc., are functioning properly. If a feeble spark appears, or none at all, each part of the system should be examined carefully.

A feeble spark or no spark from the coil may be due to:

1. Battery discharged.
2. Corroded battery terminals.
3. Short circuit, open circuit, or poor connection in primary wiring or switch.
4. Breaker not functioning properly, contacts dirty or sticking.
5. Leaky or short- or open-circuited condenser.
6. Open-circuited resistance unit.
7. Defective induction coil, or coil of wrong type.
8. Improper wiring.

196. Troubles Common to Open-circuit Breakers.—The principal causes of troubles arising in the open-circuit-type breaker (for example, the Atwater-Kent) are: (1) widening of the contact opening through wear of contacts, and (2) wearing of the striking surfaces and edges of the latch mechanism and cam, upon which depends the successful closing of the contact points. See Fig. 131.

1. *Adjustment of Contact Points.*—The contact points are made of tungsten and should be adjusted to stand open normally 0.010 in., or the thickness of a standard U. S. post card. If the contact opening is too great, the points will either not close upon release of the latch lifter, or will not close a sufficient length of time to permit the coil to magnetize fully, thus producing feeble or no ignition. The contact opening can be adjusted by the addition or removal of a washer of the proper thickness under the head of the stationary contact screw. Great care must be taken not to take out too many washers or a washer too thick (several of different thicknesses are used), or the points will be so close that the circuit will not be interrupted properly. Also, the points may stick, causing discharge of the battery and over-heating of the coil.

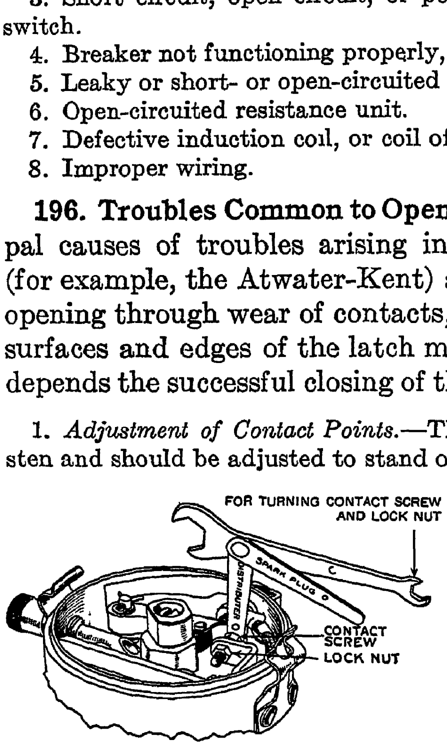


FIG. 324.—Setting breaker points using thickness gage.

2. *Procedure for Worn Parts.*—After continued service, the corner of the latch lifter which is caught and released by the cam, Fig. 131, will gradually wear down so that on the return movements of the latch lifter by the spring the latch is not hit with sufficient force to close the contacts. The only

remedy is to replace the worn lifter with a new one In case the contacts become rough and pitted, they may be smoothed by passing either a strip of fine No. 00 sandpaper or a platinum file between them.

Caution!—Since the contact points are closed only a fraction of a second, a specially fast coil is required. Therefore, if the coil must be replaced, one of the same type and manufacture should be used.

197. Troubles Common to Closed-circuit-type Breakers.—When ignition is from a battery ignition system using a closed-circuit-type breaker (for example, the Delco), the troubles which may cause misfiring, and the remedy for each, are as follows:

1. *Breaker Contact Points Dirty, Pitted, or Worn Badly.*—The points may be cleaned and smoothed by passing either a strip of fine No. 00 sand-

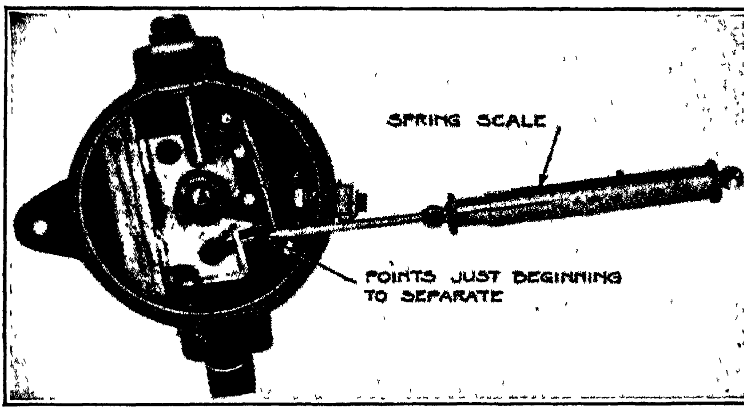


FIG. 325 —Method of testing breaker spring tension (Delco).

paper or a fine platinum file between them. The points when together should make square contact across the entire surface In case the points are so badly worn that the platinum or tungsten is worn away, new points will be necessary.

2. *Contact Points Not Adjusted Properly.*—The standard maximum opening of the breaker points when the movable contact is carried at the outer end of the contact arm is 0.015 to 0.020 in., or the thickness of the gage attached to the adjusting wrench furnished with the system. Two U. S. post cards may also be used as a gage. In breakers having the contacts supported between the pivot and cam buffer, as in the Atwater-Kent, type CC, the maximum contact opening should be 0 006 to 0.008 in.

To adjust contact opening, first set cam to give the points the maximum opening, then loosen the locknut on the stationary contact screw, retightening the locknut only after the contact screw is set to give proper opening in accordance with thickness gage, as in Fig. 324.

3. *Contact Points Out of Alignment, Due to Loose or Worn Pivot.*—Adjust by renewing bushing in contact arm or by replacing entire arm.

4. *Loose Contact Points.*—Tighten and adjust to proper opening. The movable contact is usually riveted in position; therefore, when riveting, care should be taken not to injure the contact surface which, in the case of tungsten, is very hard and brittle.

5. *Weak Spring Tension*—Weak spring tension will result in misfiring, particularly at high speed. To test the spring tension, use spring scale as shown in Fig. 325. A pull of 1 to 1¼ lb. should register on the scale at the time the contacts open The spring tension in most instances can be increased or decreased by shortening or lengthening the spring or by bending.

6. *Contact-arm Pivot Binding.*—Such a condition would interfere with the spring action and may prevent the contacts from closing. The trouble may be due to the fiber bushing in the contact arm being swollen, due to moisture, or to pitting of the pivot, caused by current passing through it. The current should be conducted from the contact arm to the ground by means of a flexible *pig tail* or spring which must make good connection.

7. *Contact-arm Buffer Worn or of Wrong Design*—When the fiber buffer becomes worn, the rubbing surface or nose may be of such length that the period of breaker contact at high speed may be reduced to a point where the coil does not have time to magnetize fully, causing feeble ignition. The remedy is either a new fiber buffer or contact-arm unit having a comparatively narrow rubbing nose.

Note.—To prevent rapid wear of the fiber buffer and rusting of the cam, a slight trace of vaseline should be rubbed on the surface of the cam each 1,000 to 2,000 miles of travel.

8. *Loose Cam.*—A cam which is not tightened sufficiently will usually be retarded in position by the drag of the contact-arm buffer causing late ignition. This is indicated by loss of power and over-heating of the engine. The ignition should be retimed and the cam tightened.

9. *Worn Distributor-shaft Bearing.*—This will cause irregular opening of the contact points, due to excessive play of the breaker housing, causing uncertain ignition. This condition is usually caused by lack of lubrication resulting in cutting or excessive wearing of the balls and races of the ball bearing. The only remedy is a new bearing. The distributor bearing should receive three to five drops of light high-grade oil each 500 to 1,000 miles of travel.

10. *Excessive Lubrication.*—Over-lubrication is to be avoided, as the oil may get on the contacts or cause electrical leakage from the insulated terminal to ground when the contacts open.

198. Condenser Troubles and Methods of Testing.—A defective condenser is indicated by serious sparking and rapid burning of the interrupter or vibrator contact points; also, by the inability of the coil to produce a hot secondary spark when the primary circuit is interrupted. If these conditions exist, the condenser

may be leaky, short-circuited, open-circuited, or of the wrong size. A condenser may become leaky through moisture, in which case it should not be used until it has been thoroughly dried out.

Testing Condenser.—A condenser may be tested as follows for:

1. Leakage.
2. Short circuit.
3. Open circuit.

1. *To Test for Leakage.*—Apply test points of 110- or 220-volt test lamp (preferably D.C.) across the condenser terminals, as in Fig. 326*A*, for a few seconds so as to charge it. Upon removal of the test points a good condenser should hold a charge at least 10 sec. and should give a good snappy spark

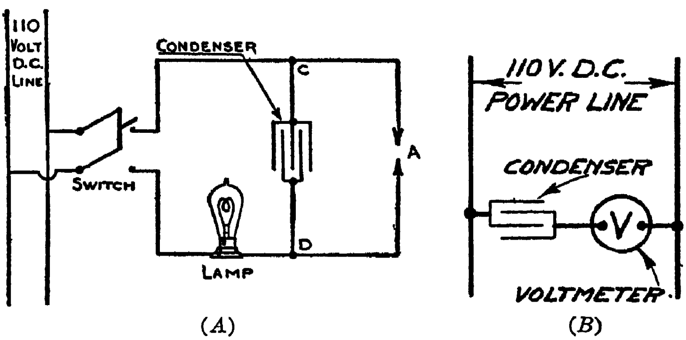


FIG. 326.—Connections for testing condenser for leakage. (*A*) Using 110-volt test lamp. (*B*) Using 110- to 150-volt D.C. voltmeter.

when the condenser leads are brought close together so as to short-circuit them. A leaky condenser will not hold a charge; therefore, no discharge spark will occur when it is short-circuited. Condenser leakage may also be detected by touching the test leads to the tongue, as in Fig. 323.

Testing Condenser with Voltmeter.—A reliable way of testing for condenser leakage, in case a suitable voltmeter of 150-volt range is available, is to connect the voltmeter in series with the condenser on a 110 volt D.C. or A.C. circuit (preferably D.C.) as shown in Fig. 326*B*. In case the condenser insulation is in good condition, the voltmeter will show no reading. If the insulation is leaky, however, the voltmeter will register in accordance with the seriousness of the trouble. If there is a complete short between the leaves of the condenser, the voltmeter will register full voltage of the testing leads.

2. *Short-circuited Condenser.*—If the condenser leakage is very great, the condenser is said to be short-circuited. This will be indicated by the glow of the test-lamp filament when the test points are in contact with the condenser terminals.

3. *An open-circuited condenser* is one in which the terminals or wire leads have become disconnected from the tin foil. Consequently, it cannot be

charged, and will not give a discharge spark when short-circuited. Another method of detecting an open-circuited condenser is to connect the condenser across the two 110-volt test points, as in Fig. 326*A*, using a 100- to 150-watt lamp, and noting the effect which the condenser has upon absorbing the arc that would normally occur when the test points *A* are touched together and then separated. A good condenser, not open-circuited, should reduce the arc from a fat, yellow, drawn-out spark to a small, bluish-white, snappy one; while a condenser that is open-circuited will have no effect on the spark.

4. *Testing by Using Spare Condenser.*—A positive test and remedy will be to replace the condenser or unit in which it is contained with another that is known to be good and of proper capacity.

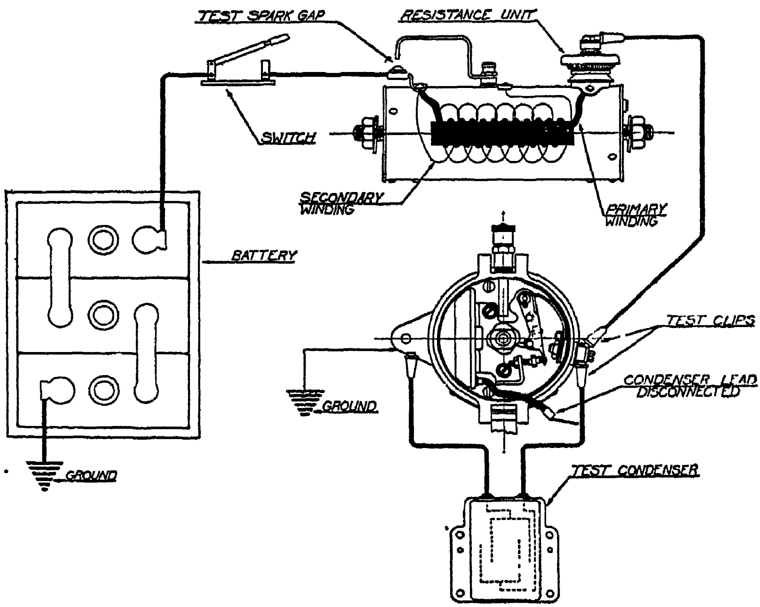


FIG. 327.—Connections for spare condenser on typical Delco ignition system. Original condenser is disconnected.

If the condenser is mounted on the breaker, a substitute or spare condenser equipped with test clips will be found convenient to connect across the breaker terminals as a substitute in place of the regular condenser. The connections for using a spare condenser on a typical Delco system are shown in Fig. 327. As shown, the original condenser is disconnected. If the spark from the coil is improved by the substitution of the spare condenser, the old condenser is unquestionably at fault. Where the condenser is mounted in the coil, it is usually quicker and advisable to substitute a new coil in case one is available.

199. The Resistance Unit.—In case the resistance unit should become burned out, or for any other reason open-circuited, the

primary circuit will be opened and no spark can be obtained at any of the plugs. This resistance unit consists of a small coil of nichrome or german-silver resistance wire, usually placed on the coil or on the breaker housing. Sometimes it is placed on the switch. In case this resistance unit should be burned out or accidentally broken, its terminals may be temporarily short-circuited with a piece of wire to relieve an emergency, but in *all such cases the resistance unit must be replaced by a good one of the proper type as soon as possible.* Continued operation without it will result in serious burning of the interrupter points and may cause injury to the coil and condenser.

A burning out of the resistance unit is often due to poor generator regulation, causing excessive voltage to be applied to the ignition primary circuit. The operator should, therefore, look for an open in the charging circuit, such as a loose connection or a corroded battery terminal, to prevent further trouble.

200. The Protective Circuit Breaker.—Wherever the protective-type circuit breaker is used, as in the Connecticut system, troubles may arise due to improper adjustment of the kick-out mechanism. In case the thermostat contacts are adjusted too close, the switch may kick out automatically (when it is not supposed to operate) with the engine running. The remedy is to increase the contact opening. It should be adjusted so that ½ to 1 min. is required after the engine stops (with the primary circuit completed) before the kick-out mechanism will operate, thus opening the circuit.

201. Testing the Induction Coil—Non-vibrating Type.—Non-vibrating coils are usually very simple in their make-up, containing only a magnetic core and primary and secondary windings. On some coils the condenser and the safety spark gap are also included in the assembly, but often either one or both of these are contained in other parts of the ignition system. The safety gap may be eliminated entirely.

A test of the proper working of the coil may be made by attaching one end of a piece of wire to the metal part of the engine and bringing the other end within ¼ in. of the secondary terminal of the coil. The breaker points in the interrupter are then closed and opened. If a good, snappy spark jumps the gap from the secondary terminal to the end of the grounded wire every time the points are separated, the coil evidently is in perfect condition and whatever trouble is present may be looked for in the other parts of the igni-

tion system. The failure of the proper quality spark to appear may be the result of any one of a number of causes, such as open-circuited resistance unit, defective condenser, broken-down insulation, or moisture.

Note—In replacing a damaged coil it is important to replace it with another of the same speed characteristics and manufacture, if possible Care should also be taken to avoid the use of a 6-volt coil where a 12-volt type is required, or a 12-volt coil where a 6-volt type is required, as the coils will not operate satisfactorily under such conditions

202. Vibrating-coil Adjustments.—A frequent cause of no spark at the plug is coil trouble, especially where a vibrating coil is used for each cylinder, as in the Ford. When the vibrator points become pitted, out of line, or burned, good contact is impossible. The tension on the vibrator spring may also become changed, permitting the coil to consume too much or too little current.

Burned or pitted points should be either filed flat with a thin, smooth file, or, preferably, a piece of No. 00 sandpaper should be passed between them. In either case the points should be shaped so as to meet each other squarely.

If it becomes necessary to adjust the tension on the vibrators, the tension should be entirely taken off and gradually increased until the engine runs satisfactorily under all load conditions with the coil consuming as little current as possible. It is important to have all the units adjusted alike. This can be done easily after a little experience. The most accurate method of coil adjustment is with a coil-current indicator, which measures the amount of current consumed. Coils are built to consume about ½ to 1½ amp.; consequently, the tension should be adjusted so that the current consumption of each coil is not much greater than this amount. Excessive sparking of the vibrator points indicates either that the points have worn down below the tungsten or platinum, or that the condenser is defective.

203. Breakdown of Coil Wiring or Insulation.—If no current is obtained in the secondary circuit of a coil when the vibrator is working as it should, the trouble is probably due either to moisture or to punctured insulation inside the coil. It sometimes happens that the binding-post wires become loosened from the post just inside of the coil housing. If only a slight spark can be obtained, the insulation on the inside wire may be broken down, thus causing a short-circuiting of the current. Obviously, there is no remedy but to replace the coil. A coil short-circuited through moisture should be dried out thoroughly before it is put back into service.

204. Timer Troubles.—A timer, such as used on the Ford, Fig. 100, may give improper ignition because of:

1 Loose terminal connections.

2 Worn timer insulation causing bouncing of roller and improper contact with all segments at high speed.

3. Worn rollers.

4 Roller arm loose on shaft.

5. Weak roller spring, preventing proper contact pressure between roller and timer segments.

6 Excessive oil and dirt in timer, preventing proper roller contact with segments.

7. Inaccurate manufacture of timer, resulting in segments or contacts unequally spaced.

8. Wrong wiring of timer

9. Timer housing retaining arm loose

Many of the above troubles are illustrated in Fig. 328.

In case the timer is worn badly, that is, the fiber and metal segments have worn down unevenly, making a series of irregularities, or "bumps," over which the roller must pass, the roller will tend to bounce over the segments without making contact, especially at high engine speeds, causing irregular ignition. The usual remedy is a new timer.

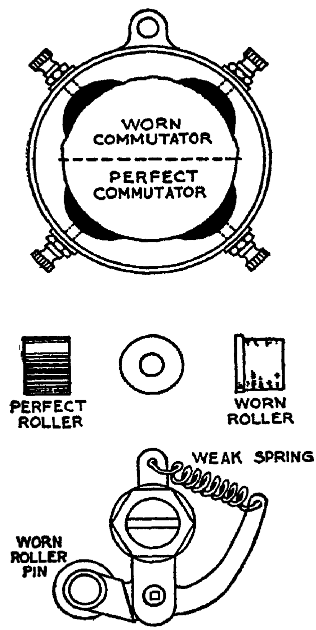


FIG. 328.—Conditions causing trouble in the Ford timer.

205. Improper Spark Timing.—If the engine kicks back when being cranked, the spark is too far advanced and should be retarded so that it will not occur until the piston has passed the dead center. The tendency of an early spark on starting is to cause the engine to kick backwards. Furthermore, too early a spark at low speeds will make the engine knock and will cause the car to jerk.

On the other hand, a retarded spark causes the engine to over-heat and lose considerable of its power. There is no advantage in retarding the spark past center, even in starting. When the engine is running, the spark should be advanced in proportion to the speed. With the spark-control lever fully retarded, the interrupter points should be timed to open (thus causing the spark) when the respective pistons are just passing the upper dead-center points at the end of their compression strokes.

On cars equipped with automatic spark advance, the troubles due to early and late spark are seldom experienced, provided the original timing of the

spark was correctly made. Preignition from other causes, however, may occur with either type of spark advance.

206. Ignition Troubles Due to Faulty Automatic Spark-advance Mechanism.—The automatic spark-advance mechanism, which is usually enclosed in the breaker housing below the cam and breaker, is liable to a number of troubles: (1) The springs may be of improper tension; (2) the lubrication may not be sufficient; and (3) the strength of the springs may not be proper for the particular engine on which the apparatus is used. Thus, the engine may require a 30-deg. spark advance at 1,200 r.p.m., while due to weak spring tension, the advance mechanism may automatically advance the time of ignition 30 deg. at 1,000 r.p.m. Obviously, the remedy would be to strengthen the spring tension of the automatic-advance mechanism. The proper advance for a particular engine can be determined experimentally only while operating the engine under load at different speeds.

In case the proper advance is hindered either by binding pivots, due to lack of lubrication, or by too strong spring tension, the engine will tend to over-heat and show lack of power at high speeds, due to operating on retarded spark. The spark-advance mechanism should receive oil each 5,000 miles of travel.

207. Premature Ignition.—Premature ignition, or preignition, is usually caused by particles of carbon, sharp corners, etc. in the combustion chamber becoming incandescent from the heat of explosion and igniting the charge on the compression stroke before the spark occurs. Preignition occurs generally when the engine is laboring under a heavy load at slow speed, such as when going up a steep hill on high gear. Any engine will have premature ignition if it becomes excessively hot under low speed and heavy load, but the tendency to preignite is much more marked if the cylinder is full of carbon deposits. The remedy is to clean out the carbon. Preignition may also be due to improper spark-plug installation, such as using a plug which extends too far into the cylinder head and which is not cooled properly.

208. Procedure in Timing Battery Ignition.—The details of ignition timing depend somewhat on the make and type of ignition system, and also on the type of engine. The general principles, however, are the same. The following rules for timing a four-

cylinder engine, with minor modifications to suit certain individual conditions, will apply generally to all makes of systems:

1. *To Time Ignition with Closed-circuit-type Breaker with Cam Adjustable on Distributor Shaft.*—Place the spark lever on the steering wheel in the fully retarded position, making sure that the interrupter timer lever is fully retarded and that all play in the connecting mechanism from spark lever to timer has been taken up.

With the petcocks open or the spark plugs removed, turn the engine over slowly by hand. After noting the firing order, either by testing the order of compression or by watching the operation of the valves, turn the engine until the dead-center mark on the flywheel for Nos. 1 and 4 cylinders (D.C. 1-4) is about 1 in. past dead-center position with No. 1 cylinder (the cylinder next to the radiator) on the upper end of its compression stroke. (One inch measured on the rim of a 16½-in. flywheel measures off about 7 deg. of the crank angle) In a four-cylinder engine the exhaust valve in No. 4 cylinder should just be closed with this setting.

Remove the distributor head and loosen the timing adjusting screw or nut in the center of the timer shaft. Turn the breaker cam so that the distributor sector, brush, or button will be in position under No. 1 high-tension terminal when the distributor head is fastened in the proper position. In this position, adjust the breaker cam carefully so that, when the distributor arm is rocked forward, taking up the slack in the gears, the contacts will be opened by the breaker cam and, when the arm is rocked backward, the contacts will close.

Tighten the adjustment screw or nut securely and replace the distributor arm and head. The head should be properly located by the locating tongue and the hold-down clips. The distributor should be wired to the plugs in the proper order of firing, beginning with No. 1 and proceeding around the distributor head in the direction of breaker-cam rotation.

2. *To Time Ignition with Closed-circuit-type Breaker with Cam Not Adjustable on Distributor Shaft.*—Follow same procedure as for breaker with adjustable cam, except that the cam position must be adjusted with respect to the engine crankshaft either by remeshing the distributor-shaft driving gears or by adjusting the coupling which drives the ignition unit.

3. *To Time Ignition with Open-circuit-type Breaker.*—In timing ignition with an open-circuit-type breaker, such as the Atwater-Kent, type K2, the general procedure is the same as in 1 and 2, except that the time of spark is set in accordance with the releasing of the latch lifter, which is the time of contact opening. This is indicated by a clicking sound each time the latch is released.

4. *To Time Ignition System Using Timer and Vibrating Coils.*—Where timer and vibrating coils are used for supplying ignition, such as in the Ford, ignition occurs at the moment the timer makes contact, due to the interrupting of the circuit by the vibrator instead of upon the opening of the contacts as in the single-spark-type system. As a rule, the roller in the timer is set so that it will be just ready to make contact with the timer segment for No. 1

cylinder when the piston in that cylinder is on top dead-center position at the end of the compression stroke, or slightly passed, and the spark-control lever on the steering column fully retarded. This setting is obtained when, with the switch on battery position, No 1 coil vibrates the instant the spark-control lever is moved in the advance direction.

209. Testing the Magneto.—If ignition is from a high-tension magneto and the spark plugs and wiring have been found in good working order, yet feeble, or no sparks are obtained at the plugs, the magneto is evidently at fault. Typical armature-type high-tension magneto circuits are shown in Figs. 226 and 244.

To determine if the magneto is generating a high-voltage current suitable for ignition, disconnect the magneto-grounding switch wire, also the distributor wire, or the distributor head, and test for a high-voltage spark across the safety gap when the armature is rotated. If the safety gap is too wide for the spark to jump at the operated speed, a temporary spark gap may be provided by resting a screwdriver blade on the magneto frame, holding the point ⅛ to ¼ in. from either the high-tension collector ring or the collector-ring brush terminal. If no spark appears across this gap when the armature is turned over briskly, the magneto is not generating sufficient voltage for ignition and should be checked for the following: (1) weak or broken magnets; (2) one magnet reversed; (3) breaker points dirty or not opening properly; (4) platinum worn away on breaker points; (5) interrupter lever worn or binding on pivot; (6) broken or weak interrupter spring; (7) defective condenser; (8) broken, loose, or dirty connections; (9) punctured coil-winding insulation; (10) excessive lubrication, causing oil on breaker points or high-tension collector ring; (11) cracked collector-ring insulation; (12) oil or carbon accumulation in distributor; (13) distributor brushes broken, missing, or with weak spring tension; (14) ground brush not making proper contact; (15) worn bearings; (16) wrong internal timing; and (17) wrong direction of armature rotation.

210. Magneto Troubles and Remedies.—The effect which the various magneto troubles have upon ignition and the usual remedy for each are as follows:

1. *Weak magnets* will cause feeble ignition at low speed and make hard starting. The magnets should be recharged to pull at least 25 lb., each being charged to as nearly the same strength as possible. Broken magnets should be replaced.

2. *A reversed magnet* will cause short-circuiting of the magnetic flux through the reversed magnet, causing little or no current to be generated by the armature. All magnets should be installed with like poles on the same side.

3. *Breaker points* adjusted too close will not interrupt the circuit properly and will cause misfiring at all speeds, while points too far apart will cause

misfiring, particularly at high speeds. The points should be kept clean, tight, and adjusted to open 0.015 to 0 020 in. They should also make square contact across the entire contact surface. If the points are rough, they may be cleaned by passing a piece of No. 00 sandpaper or a fine, thin flat file between them. A file should not be used if it can be avoided, as it wastes the platinum on the points.

4. *No platinum on the breaker points* is indicated by feeble ignition and by excessive arcing and burning of the points. Breaker points worn to this extent must be renewed. Genuine platinum points should always be used on high-tension magnetos.

5. *A worn pivot in the interrupter lever* usually gives irregular ignition, due to the resultant variable contact opening. Either the worn pivot bushing or the entire contact arm should be replaced. A pivot that binds is due usually to a fiber bushing swollen through moisture or oil, or to pitting of the pin by the current grounded improperly. The remedy is to replace either the bushing or the pin, or the entire breaker plate.

6. *A broken interrupter spring* should be renewed. If it is weak, misfiring will result at high speed, since the points are not returned to the closed position quickly enough to allow the primary current to build up to full strength before the contacts reopen. The proper tension is about 1 to 1¼ lb. with the points closed. The spring tension may be varied by shortening, by bending, or by backing up the main spring with a shorter second spring.

7. *A defective condenser* is indicated by excessive arcing and rapid burning of the breaker points. As a rule, the condenser is connected in parallel with the primary winding, so that in order to test it one lead must be disconnected. It may then be tested with a 110-volt test lamp as explained in Art. 198. If the condenser is found defective, it must be replaced.

8. *A loose or dirty connection*, particularly in the primary circuit, will give uncertain ignition. All connections should be clean and tight. If connections require soldering, use a good soldering paste instead of acid, to avoid corrosion.

9. *Punctured coil insulation* will result in misfiring, particularly under heavy compression. This trouble is usually due to running the magneto without a safety gap, with the gap set too wide, with one or more spark plugs adjusted to too wide a gap, or with wires disconnected. The safety gap should be set usually not over 5⁄16 in. A remedy for punctured coil insulation is usually either a new coil or a new magneto armature.

10. *Excessive lubrication*, as a rule, is worse than too little. Each bearing should receive only two to three drops of light high-grade oil each 500 to 1,000 miles of travel.

11. *A cracked collector-ring insulator* will cause short-circuiting of the high-tension current to the ground as indicated by misfiring under heavy compression. The only remedy is to replace the ring.

12. *Oil or carbon accumulation in the distributor* should be cleaned out each 2,000 to 3,000 miles of travel, as it may cause electrical leakage, as indicated by misfiring under heavy pull. The oil or carbon may be removed by using a rag moistened with gasoline, allowing it to dry thoroughly before operating the magneto.

13. The *distributor brushes* should be of good-quality carbon and should make good contact with proper spring tension. Broken or lost brushes should be replaced.

14. The *ground brush* is found on all armature-type magnetos using ball bearings. Its purpose is to provide a positive ground between the revolving armature and the magneto frame. If the ground brush becomes broken, disconnected, or lost, causing the primary and secondary current to seek a path through the bearings, sparking will occur, due to the poor contact caused by the oil film. This will result in carbonizing of the oil, also pitting and cutting of the balls and races. The remedy is to install a ground brush and new bearings if needed.

15. *Worn bearings* or bearings with too much play, such as may be due to magneto end plates not tightened properly, will prevent proper alignment of the armature, causing it to wobble and to strike or rub the pole pieces. It may effect the breaker point opening also. The remedy is to install new bearings and adjust breaker-point opening.

16. *Wrong internal timing* may prevent a spark entirely. Such a condition may be due to a wrong type of breaker plate, for example, a left-hand type when a right-hand type is required, or to improper meshing of the armature and distributor gears. In the armature-type magneto, such as the Bosch, Fig. 226, the internal timing should be such that, with the breaker housing fully advanced, the breaker points should open when the edge of the armature core has left the edge of the pole pieces approximately $\frac{1}{16}$ in. In the inductor-type magneto, such as the Dixie, Fig. 272, the breaker points should start to open when the edge of the inductor or rotor has left the corner of the pole 0.020 in. (or the thickness of the gage used for setting the breaker points), regardless of breaker advance or retard position.

In either type of magneto the armature or rotor and distributor gears should be meshed, so that when the breaker points are just separating the distributor brush is making contact in the middle of the distributor-head segment, with the breaker housing in the mid position of its advance and retard angle. For convenience in timing, the distributor gears usually are marked with a punch mark on each of two teeth that adjoin one another when meshed properly. The distributor teeth may also be marked with *R* and *L* or *C* and *AC* to designate the teeth which should be used for timing for right or clockwise and left or anti-clockwise armature rotation. The direction of rotation is determined by looking at the driving end.

17. *Wrong direction of armature rotation* will produce a feeble or no spark, since the breaker opens at a wrong time with respect to the generated armature current. To reverse the direction of magneto armature, the following changes usually are necessary:

In the Armature Type.—(*a*) Change breaker plate for one designed for desired direction of rotation. (*b*) Retime distributor gears. (*c*) In magnetos with specially shaped pole pieces, such as the early Bosch with comb-type trailing pole corners, and Simms with wedged or extended trailing pole corners, it is also necessary to reverse the pole pieces.

In the inductor type, as the Dixie and K-W, it is necessary (*a*) to change the breaker cam for one suitable for the desired direction of rotation, or, if of the reversible type, reverse it (turn it over) on the shaft, and (*b*) to retime the distributor.

Note.—When the cam is reversible, its two sides are usually marked either by an arrow or by *R* and *L* to indicate direction of rotation.

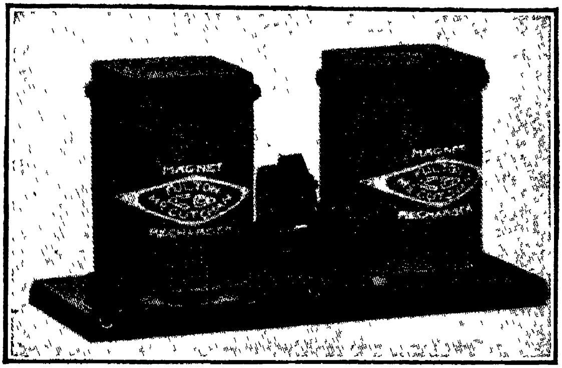


FIG. 329.—Typical electromagnet with pole pieces for recharging magneto magnets.

211. Magnet Charging and Testing.—In case the magnets on a magneto become weak so as to cause feeble ignition at low speeds, particularly upon starting, the magnets should be removed from the magneto frame and remagnetized or recharged by an electro-

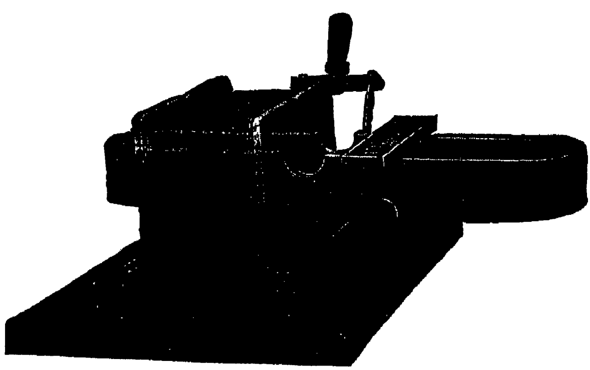


FIG. 330.—Solenoid type of magnet recharger (Splitdorf).

magnet or recharger designed for this purpose. Figures 329 and 330 show typical magnet rechargers. Figure 329 is the type more commonly used, since it is more adapted to all sizes of magnets. The recharger may be designed to operate either on

110-volt D.C. or on an automobile storage battery of the 6- or 12-volt type. The recharger should be of sufficient capacity to bring the magnet up to the full magnetic saturation point, that is, to its maximum pull per square inch of pole area. This usually requires 12,000 amp.-turns on the recharger for ordinary magnets and 5,000 for Ford magnets.

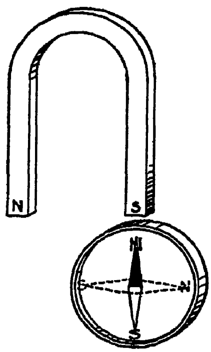


FIG. 331.—Determining polarity of magnet using pocket compass.

To charge a magnet, place it on the poles of the recharger so that the magnetic lines of force will pass through the magnet in the same direction as it was originally magnetized, that is, the north pole of the magnet will be on the south pole of the recharger and the south pole of the magnet on the north pole of the recharger. The proper position for the magnet can be quickly determined by holding the magnet above the recharger and closing the switch. The magnetic attraction between the north and south poles will tend to swing the magnet to the correct position. The polarity of the poles may also be determined by using a pocket magnetic compass, as the north pole of the compass will be attracted by the south pole of the magnet, as in Fig.

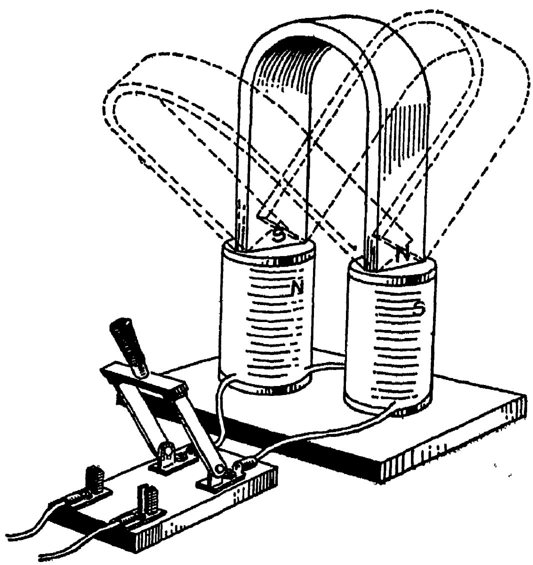


FIG. 332.—Method of recharging magneto magnet.

331. In many cases the north poles of the magnet are marked with an *N* or punch mark. These markings, however, cannot always be depended upon and should be checked in all cases to see if the magnetism has been reversed.

With the magnet properly placed on the recharger and the current turned on, it should be either rocked back and forth a few times, as in Fig. 332, or hit several blows with a light hammer to assist the molecules of the magnet to arrange themselves so as to give the greatest magnetic strength. Usually the current may be turned off in 10 to 20 sec., after which the magnet should be supplied with a *keeper*[1] and removed for testing.

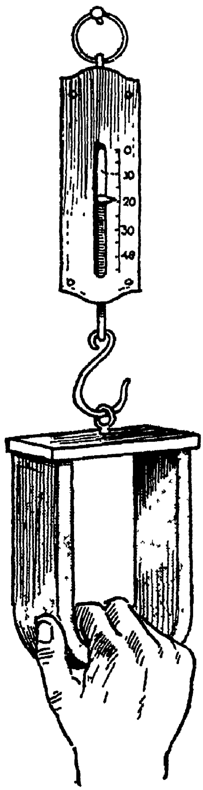


FIG. 333.—Method of testing pull of magnets using spring scale and keeper.

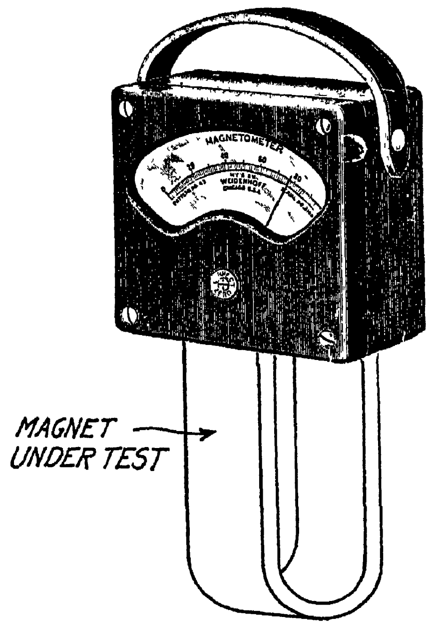


FIG. 334.—Magnetometer for testing strength of magnets.

To Determine Pull of Magnet.—A simple method of determining the magnetic pull of a magnet is to use a spring balance of a capacity of 50 lb.

[1] *The keeper* is a piece of soft iron or steel placed across the poles of the magnet to provide a path for the magnetic lines of force of the magnet, thereby helping to maintain its strength. The keeper should not usually be removed until the magnet is to be placed on the magneto. It is then removed as the magnet is slipped into place, but it should be pulled straight off and not shifted toward the arch of the magnet, as it will weaken the magnet strength.

attached to a keeper as shown in Fig. 333. With the scales supported by a hook, pull down on the magnet and note the scale reading at the instant the magnet breaks from the keeper. This reading minus the weight of the keeper will be the pull of the magnet measured in pounds. Another method used for testing magnets is to use the instrument known as a magnetometer, shown in Fig. 334. In using the magnetometer the case of the meter is usually placed in contact with the magnet pole and the needle deflection indicates on the scale the strength of the magnet. This method is usually considered preferable, as there is no making-and-breaking of the magnetic circuit and consequently no loss in magnet pull as in the springscale-keeper method.

The average-sized magnet, composed of tungsten steel as used generally on modern high-tension magnetos, should pull 25 to 35 lb. when fully magnetized. Ford magnets (¾-in. size) should pull 5 to 6 lb. each. If two or more magnets are used, all magnets should be charged to as nearly the same strength as possible.

Caution!—Care should be taken not to pound a magnet after charging, as the vibration will cause it to lose strength. The magnetic strength will weaken each time the keeper is removed, and also, when the magnets are placed together so that they stick and are then broken apart without a keeper on each.

212. Charging the Ford Magneto.—The principles involved in charging the magnets of the Ford magneto are the same as applied to any magneto magnet. Owing to their number and location on the flywheel, however, it is somewhat inconvenient to charge them, as it involves taking out the transmission.

As will be recalled from the study of the Ford magneto, there are 16 V-shaped magnets mounted on the face of the flywheel. The magnets measure ⅝ by ¾ in. in cross-sectional area and should, when fully charged, have a pull of 5 to 6 lb. each. In case they should become weakened, say, down to a pull of only 3 to 3½ lb. or where the magneto terminal voltage is less than 10 volts when running, the engine will be found to start hard and ignition on magneto will be feeble at low speeds. Consequently, should the magnets be reduced in strength to this hard starting point, they should be either renewed or recharged. When the magnets are in good condition, the magneto voltage should be 15 to 25 volts at normal driving speeds. The voltage should be tested with an A.C. voltmeter.

Charging on the Car.—A scheme often used by service stations to save time and expense is to charge the magnets in position on the flywheel. Two plans of procedure are possible, namely, (1) passing current through the magneto coil-plate winding from a set

of storage batteries, the magnetizing effect of the magneto coils being utilized to charge the magnets; (2) to use a specially constructed magnetizing unit, as shown in Fig. 335. This is inserted through the hand hole in the flywheel housing and the poles of the charger are applied to the poles of the magnets. Either method is more or less of a makeshift and cannot always be depended upon to produce the desired results. When the magnets are recharged by bringing them into contact with the poles of the special magnetizer (Fig. 335), care should be taken always to apply the north pole of the magnetizer to the south pole of the magnets in order to send the magnetizing field through the magnet in the proper direction. Since the magnets on the

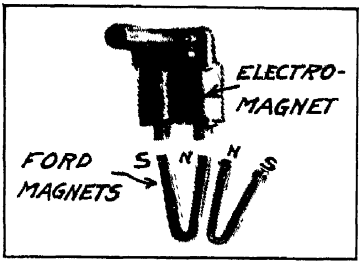


FIG. 335.—Electromagnet for charging Ford magnets in position.

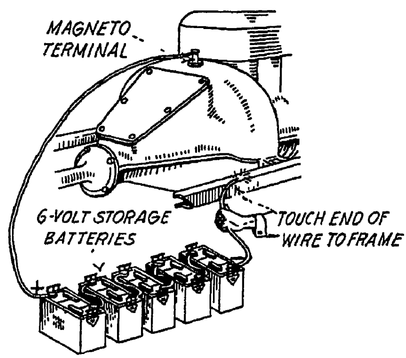


FIG 336.—Arrangement of batteries to charge Ford magnets by sending current through coil plate

flywheel alternate in position, the magnetizer must be reversed in position with each adjacent magnet that is charged in order to have all the north and south poles together.

Several difficulties are encountered with this method of charging. (1) The magnets on the flywheel are all joined by iron plates which act as pole faces; therefore, there will be more or less magnetic leakage through all the remaining 15 magnets, thus decreasing the field strength through the magnet being charged. (2) The ends of the magnets are pinched off in the making so that they will not make square contact with the poles of the magnetizer, thus decreasing the effective magnetic flux through the magnet. (3) There will be a leakage of magnetism from the magnets and poles through the cores of the coil plate. If the magnetizer is of sufficient strength, however, 5,000 amp.-turns or over, it is possible to boost the strength of the magnets to aid ignition materially

The other method of charging the magnets on the car, that is, sending current through the magneto winding, involves considerable care—otherwise more damage may be done than good. The equipment needed consists of a pocket compass to determine the polarity of the magnets and six fully charged 6-volt storage batteries of at least 40 amp.-hr. capacity wired in series as shown in Fig. 336. The positive lead from the battery is connected to the magneto terminal (disconnecting the magneto wire), while the negative lead is left free to make striking contact on the car frame. Before the battery circuit is completed, the magnets must be carefully located so as to have the poles in the proper position with respect to the cores of the coil plate. This is best accomplished by holding a small pocket compass 1 in. to the left and 6 in. to the rear of the magneto terminal as shown in Fig. 337.

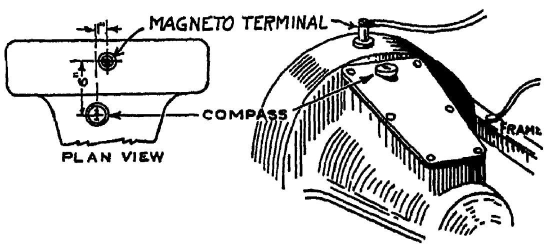


FIG. 337.—Setting Ford magneto for recharging magnets.

The engine is then slowly cranked until the north end of the compass needle points straight toward the front end of the car or, in reality, to the south pole of the magnet just to the left of the magneto terminal. The positive wire from the batteries is then connected to the magneto terminal on the flywheel housing, but care should be taken to make sure that the magneto wire is disconnected from the ignition and lighting system. The negative lead from the batteries should then be touched two or three times to the car frame for about a second. The arc which forms when the connection is broken should be pulled out slowly.

Each coil of the magneto coil plate will act as an electromagnet and tend to build up the strength of the magnets. With this arrangement, about 40 to 50 amp. will pass through the magneto coils and, if the magnets are lined up as previously described, each coil will act to charge one magnet, there being 16 coils and 16 magnets.

The results obtained from this method of charging are often not satisfactory. Therefore, it should not be depended upon for a high-grade job, but used only for "getting by" temporarily, should the owner not desire either to lay up his car for the time required to take the magnets out, or to incur the expense of having the magnets charged properly. The reason why this scheme is not always satisfactory is that there is an air gap of approximately $\frac{1}{32}$ in. between the coil plate and the magnets, thus preventing metallic contact, and because of the lack of sufficient ampere-turns in the coils to produce sufficient magnetic pull to bring the magnets up to the full saturation point. There is also the danger of burning out the coil winding in case the insulation is in poor condition, or the current is left on for too long a period.

Caution!—There will be a heavy flash each time the cable is touched to the frame, so that care should be taken to see that there are no oily rags or gasoline about to catch fire

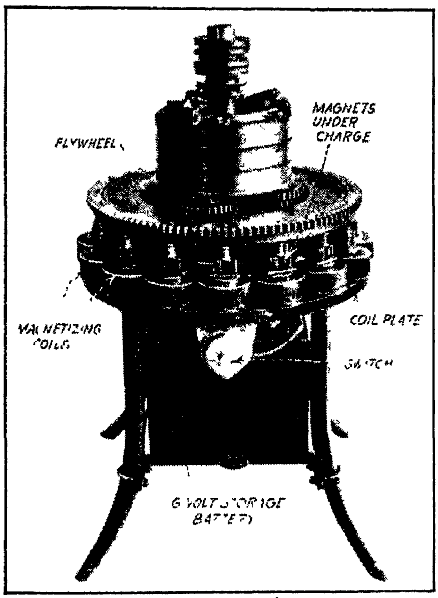


Fig. 338.—The Madison Ford unit magnetizer.

The Madison Magnetizer for Ford Units.—Probably the most satisfactory method for charging the Ford magnets with the minimum of labor and expense, especially when the car is being overhauled and the transmission is out, is by the Madison Ford unit magnetizer, Fig. 338. With this outfit, the entire magneto, together with transmission, may be placed with the magnet poles over the poles of the charger, and the entire lot of 16 magnets charged at one time by the closing of the battery circuit. An ordinary fully charged Ford storage battery supplies the current, the circuit being completed by the closing of a starting-type switch mounted

on the lower side of the coil plate. The magnetizing coils are constructed with the proper ampere-turns and the core plate of special dynamo steel, so that the magnets will be charged to full saturation point upon closing the starting switch for only an instant two or three times.

It has been found that magnets charged in this manner will have a pull of approximately 6 lb. from the pole faces compared with 5 lb. as sent out by the factory. This method of charging also arranges the molecules in the magnets in the best alignment to give efficient service.

213. Magneto Timing.—The procedure for timing the usual high-tension magneto to the engine is similar to the procedure for timing the battery ignition system. With the engine set with No. 1 piston on top dead-center firing position, the armature should be set so that the breaker points are just ready to open with the breaker housing fully retarded and the distributor brush or segment in contact with the spark-plug terminal for No. 1 cylinder. The magneto is then connected to the engine through the driving coupling without disturbing the armature position. A dual type of high-tension magneto should be timed with respect to the battery breaker, as the magneto breaker is usually timed to open 10 deg. earlier.

SECTION XIII

STORAGE-BATTERY CONSTRUCTION AND OPERATION

214. The Automobile Storage Battery.—The function of the storage battery on the modern automobile is to act as a reservoir from which electric current may be used for various purposes when the demand is greater than the supply. When the engine is running and the generator is producing more current than is being used for the ignition, lamps, horn, and other electrical accessories, the excess current passes through the battery, causing it to store up energy in the form of chemical energy. Then, when

FIG. 339—Typical 6-volt automobile battery—square type

the generator is not running, or is not producing the amount of current needed to supply the demand, the battery simply discharges enough to make up the difference. The starting motor, due to its high-current consumption, is the greatest load which the storage battery must take care of; therefore, if the battery is designed to handle the high-discharge rates required during the cranking periods, it naturally will be capable of taking care of all other demands without difficulty.

The only type of storage battery which has been found satisfactory for automobile starting, lighting, and ignition service is

the lead-acid type, in which lead plates and sulphuric acid are the chief elements. The principles of this battery were discovered originally by Planté, a Frenchman, who in 1860 made the first practical battery from lead strips and dilute sulphuric acid. Planté's battery, which proved to be very heavy and not capable

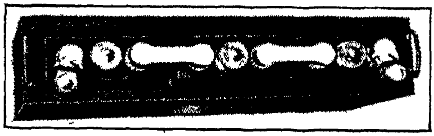


FIG. 340.—Six-volt battery—long type.

of high-discharge rates, was later improved upon by Fauré, another Frenchman, who in 1880 introduced the pasted-type plate now so generally used in storage-battery construction.

When charged, each lead-acid storage cell produces a voltage of approximately 2 volts. Thus, a battery of any voltage of the multiple of 2 may be made by connecting the required number of

FIG. 341.—Typical 12-volt automobile battery.

cells in series *i.e.*, connecting the positive terminal of one cell to the negative of the next.

For automobile service the three-cell 6-volt battery has been adopted generally as standard equipment, although a few car manufacturers still use batteries of higher voltage, namely, 12 volts. The 6-volt battery is popular because, with its voltage and

number of cells, maximum current capacity may be obtained with minimum weight, cost, and service expense. As previously stated, however, the 12-volt battery is also used, usually in connection with single-unit starter generators where it is highly desirable to obtain high-cranking torque and to reduce the size and weight of the starting equipment to a minimum. In Fig. 339 is shown a typical 6-volt starting battery with the cells arranged side by side in the box, while Fig. 340 shows a similar battery of the long type having the three cells arranged end to end. The long battery is designed particularly for mounting along the running board or side frame of the chassis, while the square type is usually mounted under the seat or hangs from the chassis

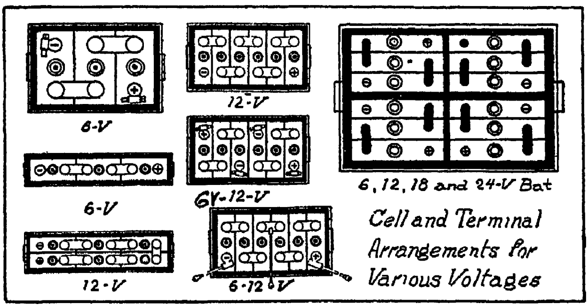


FIG 342—Cell arrangement of typical automobile batteries.

frame or car body. An example of the 12-volt battery is shown in Fig. 341, which shows the Willard battery for the Dodge car.

In the past, many shapes, cell arrangements, voltages, etc have been used, as is indicated by the batteries shown in Fig 342. The trend today, however, is to standardize on the three styles mentioned above in order to permit interchangeability and to reduce manufacturing and service costs to a minimum.

215. General Construction of the Automobile Storage Battery.—A sectional view of a typical automobile storage cell, showing the general construction, arrangement, and names of parts, is shown in Fig. 343. Each cell contains five fundamental battery parts, namely, (1) the positive plates; (2) the negative plates; (3) the insulation between the plates; (4) the electrolyte or battery solution; and (5) hard-rubber jar. Each part will be explained in detail under separate headings.

A cell ready for assembly in a wood case is shown in Fig. 344. As will be noted from Fig. 343, the cells, after being assembled in

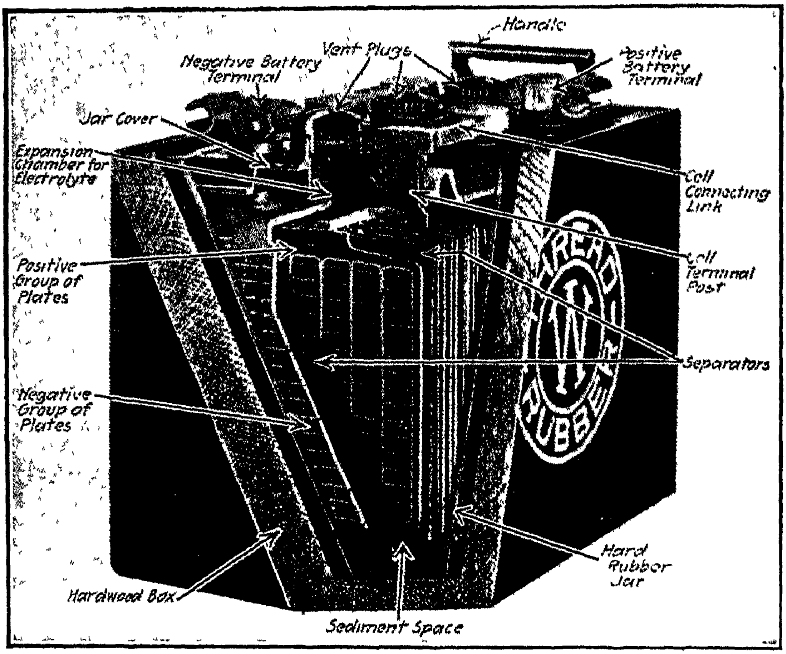


FIG. 343.—Section of typical automobile storage battery (Willard).

a protective case of wood or of molded rubber, are connected in series by short heavy bars of lead called the *top connectors*. After all the connectors are in place, a positive post of one cell and a negative post of another are available as battery terminals. These terminal connectors connect the battery to the electric circuits of the car.

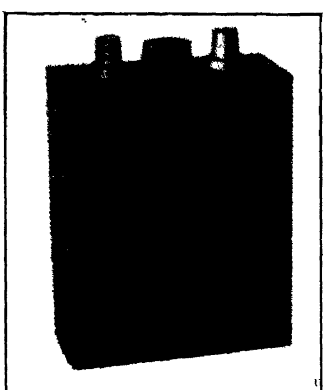


FIG. 344.—Storage cell ready for assembly in wood case.

216. The Plates.—The plates comprise the most important part of the battery, since upon their construction, composition, and characteristics depends the performance of the entire battery. The principal parts of each plate are the *grid* and the *active material* which it contains.

Grids.—Types of grids are shown in Fig. 345. The grid, which serves as a backbone and provides strength to the plate, is composed chiefly of lead with about 5 to 12 per cent antimony alloyed with it to increase its strength. In addition to acting as a support for the active material, the grid must also serve as a conductor for conducting the current to and from the active

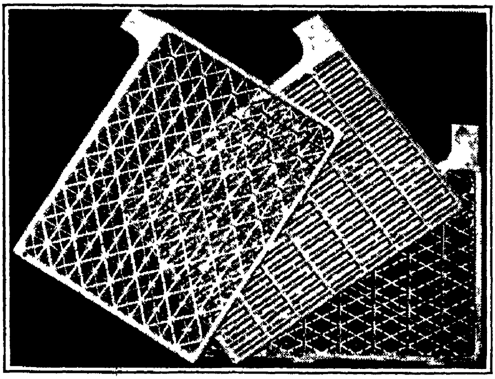


Fig 345.—Types of grids for battery plates

material in the plate. The contact or bond between the active material and the grid, therefore, should be very good to avoid excessive internal plate resistance.

The design and the weight of the grid are also important, since upon these factors depend not only the strength of the plate and its ability to withstand bending, but also the amount of active material which the plate can hold. Naturally, the more metal there is in the grid, the less active material a plate of a definite thickness, length, and breadth can hold.

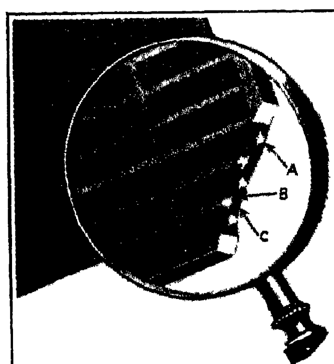


Fig. 346.—Magnified view of battery plate showing grid.

Many types of grids have been introduced upon the market in an attempt to produce a grid of maximum strength with respect to its weight and capacity for holding active material. Some have the ribs running vertically and horizontally, while others have them running diagonally also, as may be seen in Fig 345. The advantage claimed for the diagonal-rib—often called the "diamond-grid"—construction is its greater resistance against warping or buckling. On the other hand, this construction does not usually lend itself to the manufacture of "thin" plates as advocated for certain kinds of battery service. Thus, the type of grid is largely governed by the desire of the manufacturer to produce a thick or a thin plate.

The Active Material.—As previously stated, Fauré devised the scheme of supporting specially prepared lead compounds or *active material* by a grid, thus developing the so-called *pasted* plate. The active materials as pasted into the grids are red lead (Pb_3O_4) in the positive and litharge of lead (PbO) in the negative, mixed with sulphuric acid and water into a stiff paste. The pasting may be done either by hand or by machine, but most manufacturers prefer the hand method to insure uniformity. A cross-sectional view of a typical plate, showing how the active material is supported by the grid, is shown in Fig. 346.

When the paste dries in the grid it becomes hard like cement, attaching itself to the many ribs of the grid. At this stage the active material in both plates is of a peculiar chemical composition, consisting largely of sulphates of lead produced by the combining of the lead compounds with the sulphuric acid. The positive plate will be bright red in color and the negative a yel-

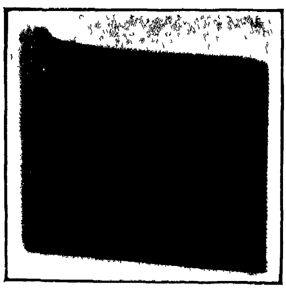


FIG. 347.—Positive plate.

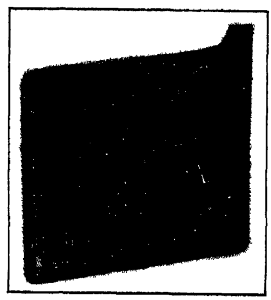


FIG. 348.—Negative plate.

lowish gray. The plates are then put through an electrochemical process known as *forming*, which consists of submerging the plates in sulphuric acid and water and passing a direct current through them, the current flowing in at the positive plate and out at the negative. This process converts the active material of the positive plate into lead peroxide (PbO_2), chocolate-brown in color, and the negative to spongy metallic lead, dark gray in color. The positive and negative plates, Figs. 347 and 348, are then ready for use.

217. Positive and Negative Groups.—After the positive and negative plates have been formed they are built into positive and negative *groups*, shown in Figs. 349 and 350. The *positive* group consists of one or more positive plates burned (welded) to a *post strap*, Fig. 351*A*, while the *negative* group consists of two or more negative plates burned to a similar post strap, as shown in Fig. 351*B*. Each strap has a post attached to it by which electrical connection is made either to the adjoining cell or to the connecting terminal. The plates are burned to the straps at the proper dis-

tances apart, so that, when the groups are assembled, as in Fig. 352, there is sufficient room between the plates to admit one plate of the opposite group and two separators.

When the positive and the negative groups are assembled with the separators, as in Fig. 353, the assembly is called an *element.*

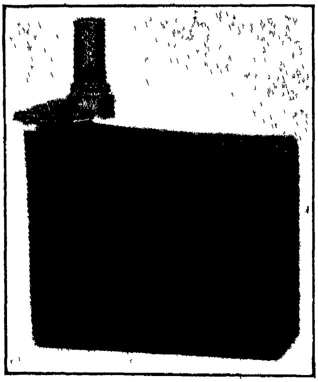


FIG. 349—Positive group.

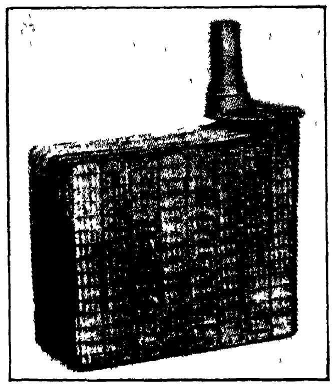
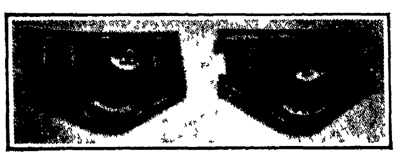


FIG. 350—Negative group.

From Fig. 353 it will be seen that each positive-plate surface is adjacent to a negative-plate surface but insulated from it by a separator. The distance between the two plate surfaces is usually about $\frac{3}{32}$ in., or approximately the thickness of the separator. It will also be noted from Fig. 352 that there is one more plate in the negative group than in the positive. This is true of



(*A*) (*B*)

FIG. 351.—Post straps. (*A*) Positive. (*B*) Negative.

all lead-acid automobile-type batteries, regardless of the number of plates used in the element. For example, a seven-plate element has three positive and four negative plates, an eleven-plate element has five positive and six negative plates, etc. Therefore, all automobile batteries will be found to have an odd number of plates per cell, such as 7, 9, 11, 13, and 15, in

accordance with the capacity desired, the purpose being to have a negative plate adjacent to the surface of each positive—the more active plate—in order to obtain the maximum efficiency from the groups.

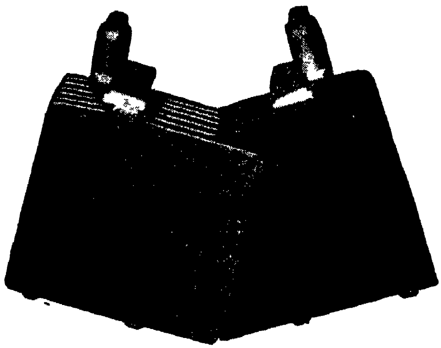


FIG. 352.—Method of assembling positive and negative groups.

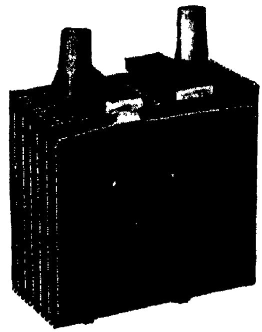


FIG. 353.—An element.

218. Separators.—The separators play an important part in the life and performance of the battery, since their function is to prevent the formation of internal short-circuits between the plates. They must be of such porosity as to permit ready diffusion

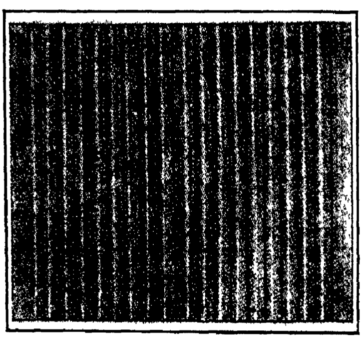


FIG. 354*A*.—Wood separator.

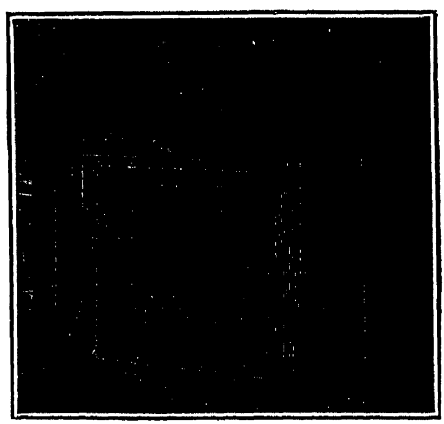


FIG. 354*B*.—Method of installing separators.

of the electrolyte, so as to offer minimum internal resistance to the passage of current through them; also, of such design as to permit free circulation of the electrolyte. The separator is also intended to prevent, so far as possible, the active material

from falling out of the plates, since the loss of this material would decrease the plate capacity.

The materials used for separators may be grouped as follows: (1) wood sheets, (2) a combination of wood sheets and thin perforated sheets of hard rubber, commonly called *retaining walls*, and (3) the threaded-rubber insulators. The latter material eliminates the use of any wood sheets.

The Wood Separator.—A typical wood separator is shown in Fig. 354*A*. It consists of specially selected and treated wood about 5/64 in. in thickness with grooves milled on one side only, as shown. When installed in the element these grooves are placed next to the positive plates, Fig. 354*B*, and running vertically, so as to provide proper circulation of electrolyte and escape of the gases produced at the positive plate upon charge and discharge. The kinds of wood usually used for separators are cedar, cyprus, and basswood, although redwood, fir, poplar, and cherry are also used. The wood

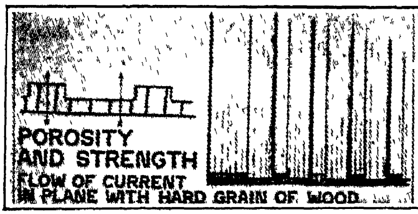


FIG. 355 —End view of wood separator showing proper direction of grain.

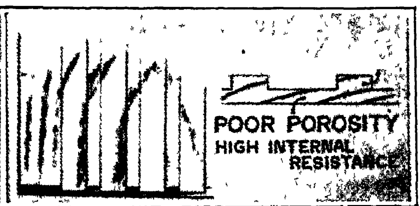


FIG. 356 —End view of separator showing improper grain of wood

generally accepted as the best is Port Orford cedar—so called because it was first made into separators at Port Orford, Ore —because of its high crushing and shearing strength, its high porosity, and its ability to withstand the action of the acid.

The wood to be used for separators must be specially selected so as to be free from knots. The sheets are generally sawed, instead of shaved, from the log—as is done for the veneer used for furniture—to insure against the stressing and tearing of the fibers on one side of the sheet more than on the other, which would cause curling of the separator, and the formation of cracks, when the sheet is made to lay flat. When sawing the separator from the log it is also important to take into consideration the annular growth marks in the wood, since the direction of these marks affects the electrical resistance of the wood. The new wood, or *spring-wood*, which is formed in the spring of the year, is softer, due to its more rapid growth, than that formed during the late summer and fall. This softness causes veins of greater porosity and, consequently, paths of lower resistance through the separator. The separator shown in Fig. 355, for example, will offer lower electrical resistance than the one shown in Fig. 356, since the growth marks—the paths of low resistance—are much shorter, thus reducing the

distance the current must travel in passing through the separator. The separator will also have greater crushing resistance, since the hard strong veins of summer wood are more perpendicular to the surfaces of the separator.

After the wood separators are grooved and cut to the proper size, they are then treated chemically to remove any substances contained in the wood, particularly acetic acid, which would be harmful to the operation of the battery. This treatment also renders the wood more porous. The separator is then ready for use and should be kept from drying out by placing it in water until used. If the separators are stored in water for any length of time, they sometimes become slimy or moldy. This may be prevented by adding a small amount of sulphuric acid to the water in which they are stored.

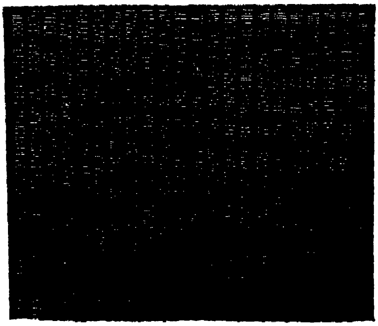
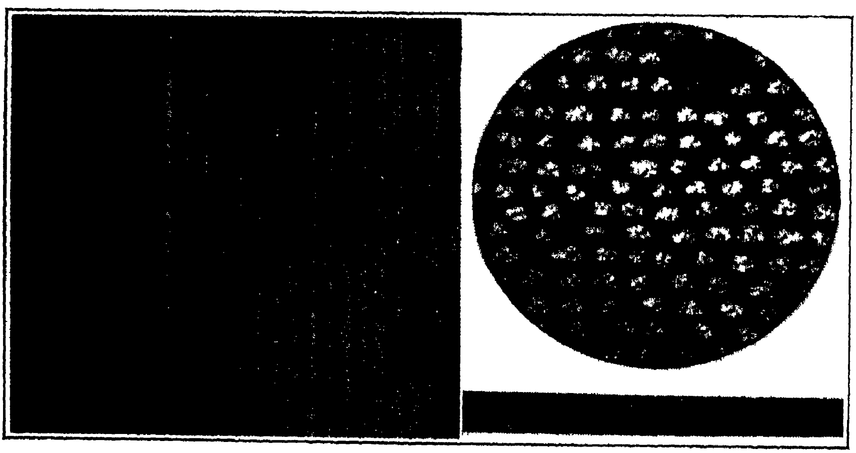


FIG. 357.—Rubber retaining wall (Philadelphia).

Wood Separators with Retaining Walls.—Thin perforated rubber sheets, known as *retaining walls*, Fig. 357, are sometimes used with wood separators These sheets are approximately $\frac{1}{64}$ in. in thickness and perforated with many small holes or slits to make them porous. They are installed next



(A) (B)

FIG. 358.—Willard threaded separator. (A) Side view. (B) Magnified surface and cross section.

to the positive plate, the object being to prevent the active material from dropping out. This advantage, however, is partly offset by an increase in separator resistance and, consequently, a decrease in battery voltage, particularly during cranking periods at low temperatures.

Threaded-rubber Separators.—The Willard Threaded-Rubber separator, developed and used by the Willard Storage Battery Company, is shown in Fig 358*A*. From the magnified view of this separator shown in Fig. 358*B*, it will be noted that the rubber is penetrated by a large number of short threads which run perpendicular to the surface. In the usual size separator it is claimed there are approximately 196,000 of these threads, making an average of 6,533 threads per square inch. The theory is that, because of capillary attraction, each thread acts as a wick between the positive and the negative plates The separator is thus rendered porous, permitting ready diffusion of the electrolyte; yet the holes are filled with the threads (which do not fall out from the action of the acid as might be supposed), thus preventing the active material from bridging or "treeing" between the plates. The threaded-rubber separator has ribs and corrugations—which correspond to the grooves of the wood separator. When installed, these ribs should be placed next to the positive plate and should run vertically.

219. The Electrolyte.—The electrolyte used in automotive lead-acid storage batteries consists of a mixture of chemically pure sulphuric acid (H_2SO_4) and distilled water, the proportion being about two parts of acid to five parts of water by volume. The proportion of water and acid should be such that the density of the solution will be at a specific gravity of 1.280 to 1.300 at 70 deg. F.

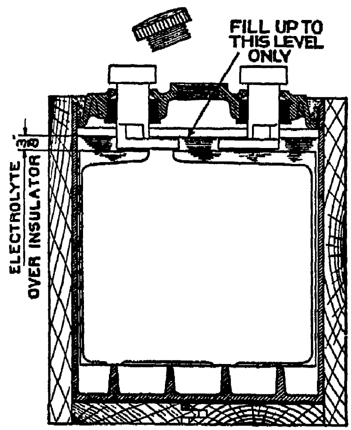


FIG. 359.—Section of storage cell showing proper level of electrolyte.

Specific Gravity.—By "specific gravity" is meant the ratio of the weight of any substance to the weight of an equal volume of pure water at normal temperature and pressure. Pure water has a specific gravity of 1, usually written 1.000, and spoken of as *ten-hundred.* One pound of water has a volume of approximately one pint. An equal volume of chemically pure sulphuric acid weighs 1.835 lb. Chemically pure sulphuric acid has, therefore, a specific gravity of 1.835 and is spoken of as *eighteen thirty-five.* The specific gravity of the battery solution may be tested readily by a special hydrometer.

Height of Electrolyte.—The level of the electrolyte at all times should be from 3/8 to 1/2 in. above the tops of the plates and separators, as shown in Fig. 359, to prevent injury to the plates and separators.

220. Jars.—The jar, Fig. 360, which forms the container for the element and electrolyte is made of hard rubber for automotive-type batteries, and of glass for farm-lighting or power batteries

which are not subjected to serious vibration. Not only must the jar withstand the chemical action of the acid, but in automotive service it must be of sufficient strength to carry the heavy weight of the element and to withstand the continuous vibration to which it is subjected.

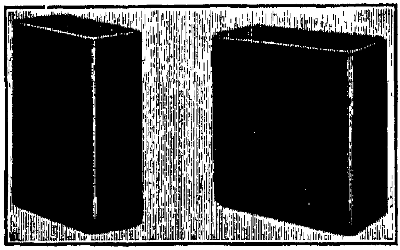


FIG. 360.—Rubber jars.

To strengthen the bottom of the cell, several bridged supports or ribs about 1 in. deep are molded in the jar, as shown in Fig. 361. These ribs not only support the element but provide sediment spaces for collecting any active material that may free itself from the plates, thus preventing it from short-circuiting the bottom edges of the plates.

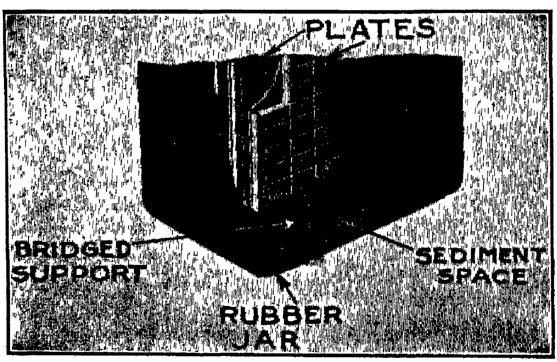


FIG. 361.—Section of storage cell showing bridged supports and sediment spaces.

221. Covers.—The cell cover provides a means of closing the top of the cell to prevent spilling of the electrolyte and to keep out objectionable dirt, water, etc. It is usually molded of hard rubber in one piece, such as Fig. 362, and shaped so that when in

position it provides an expansion chamber for the electrolyte. It has an opening in the center for the vent plug and an opening on each side to fit over the cell posts with provision for sealing against leakage.

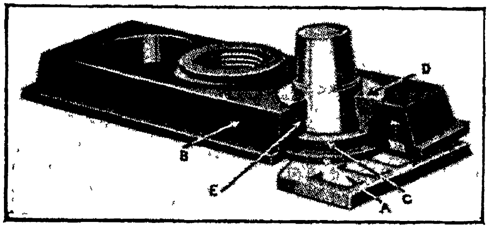


FIG. 362.—Typical cell cover (Universal).

Figures 362 and 363 show typical methods of sealing the post to prevent leakage of the electrolyte at this point. The more common method is to use a rubber gasket held tight either by a binding nut on the post or by swedging down a lead collar or wedge. Sealing compound is often depended upon to make the seal, but, unless the sealing is carefully done, leaks tend to form, due to the compound breaking away from the post. This is more likely to happen in cold weather, especially if the post is not entirely rigid. By pouring hot sealing compound in the V-shaped space around the edge of the cover, a leak-proof seal is formed between the cover and the jar.

The center opening of the cover, or *vent hole*, is fitted with a vent plug de signed so as to permit the escape of any gas which may form within the cell, and to prevent spilling of the electrolyte. By removing this vent plug, water or electrolyte may be added to the cell. It also affords an ppening through which the electrolyte may be tested.

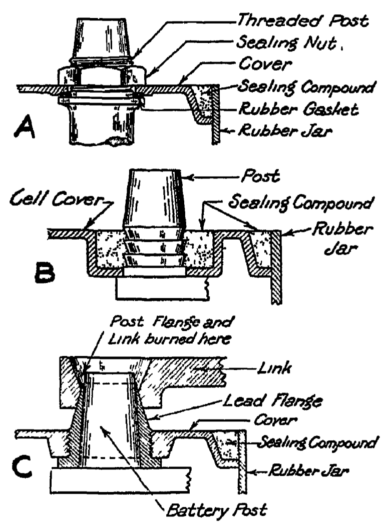


FIG. 363—Methods of sealing cell post with cover.

222. The Battery Box.—For automobile service the cells are assembled in a suitable box or case, as shown in Fig. 343, which holds them rigid and provides protection against mechanical injury. The case is made usually of hardwood and is thoroughly coated inside and out with an acid-proof paint; however, special molded rubber cases may be used.

The wood box is usually constructed with dovetailed corners held together with wood pins. All screws and bolts used are lead-coated so as to withstand the corrosive action of the acid. Handles for lifting the battery are fastened to each end of the case, as in Fig. 339. In most cases, hold-down bolts clamp over the handles to fasten the battery firmly in position in the car. The handles and hold-down bolts and clips should be lead-coated to prevent corrosion by the acid.

The Molded Battery Case.—A battery case has recently been developed and adopted by several leading battery manufacturers, which is made of molded hard rubber formed under pressure, the cell partitions being in one piece with the walls and the bottom. Figure 364 shows the Monobloc case as used by the Willard Battery Company. This case has metal handles, while the Rub-Tex case, shown in Fig. 365, has the handles molded as a part

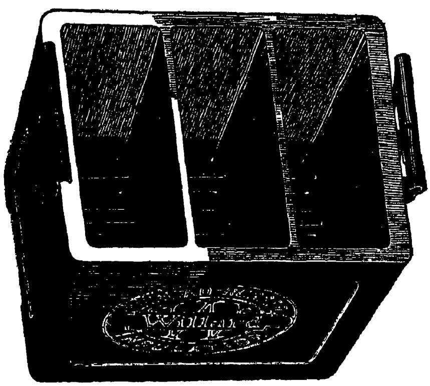


FIG. 364.—The Monobloc rubber battery case (Willard)

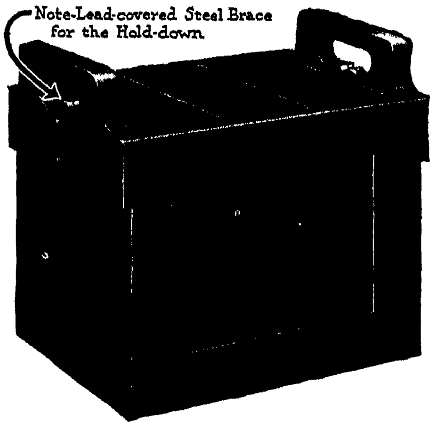


FIG 365 —The Rub-Tex battery case

of the box. Besides eliminating the separate rubber jars for each cell, this new case is not affected by acid, dirt, water, or oil. Also, it does not permit electrical leakage through the case to the car frame, as often happens with acid-soaked wood cases. If properly constructed and installed, the rubber case should have greater life than the wood case. Its cost of manufacture, however, is somewhat higher.

223. Cell Connectors.—The cells are usually arranged in the case in such a manner that the positive post of one cell is adjacent to the negative post of the next. The adjacent cells are then permanently connected in series by short, heavy lead bars, or *top connectors*, as shown in Fig. 366. This illustration shows the burned-on type of connector, which is used commonly for start-

ing type of batteries, the connectors being welded or "burned on" by an oxy-acetylene or a hydrogen torch.

The *bolted-on* or strap type of connector, Fig. 367, has also been used to some extent. These connectors consist of lead-coated flat copper strips held in place by stud bolts, the heads of which are lead-coated to prevent corrosion from the acid. For batteries intended only for ignition and lighting service, where the discharge rate is fairly low, slender connectors of lead fastened to the terminal posts by lead-coated screws or bolts may be used. This construction makes it easy to take the battery apart for repairs, but, on the other hand, it is more difficult to maintain clean, tight cell connections—a trouble not experienced with the burned-on type of connector.

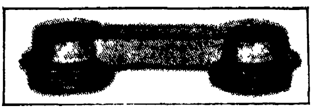


FIG. 366—"Burned On" type of cell connector

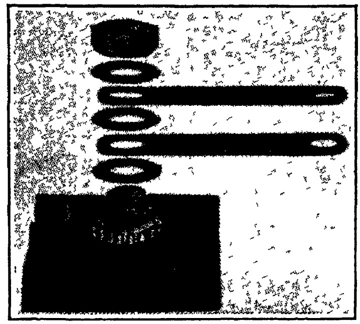


FIG. 367.—Parts for "Bolted On" cell connector.

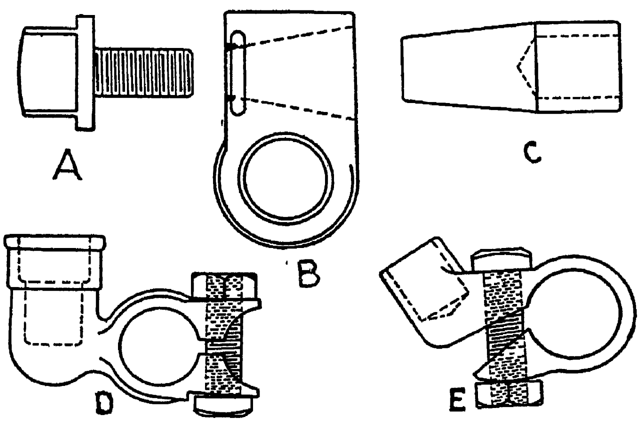


FIG 368.—Types of battery terminals (*A*, *B* and *C*) Parts of thimble type. (*D*) Clamp terminal for standard taper. (*E*) Clamp terminal for straight post.

224. Terminals.—Typical terminals for connecting the starting cables to the battery, are shown in Fig. 368. *A*, *B* and *C* show parts of the *burned-on* thimble type in which the cable end makes a taper fit with the post terminal; *D* shows the

clamp type for tapered posts; and *E* shows the clamp type for straight posts. The burned-on type of terminal has been used extensively in the past, but has practically given way in favor of the clamp type, since the former requires special burning on of the terminal to suit the lay of the connecting cable, which differs widely on the different cars. This problem is overcome by the use of the clamp-type terminal, since it permits adjustment of the cable to any desired horizontal position by loosening the terminal bolt.

Size and Markings of Terminal Posts.—Irrespective of the type of terminal used, it is common practice to make the positive post and terminal connection slightly larger than the negative as a ready means of identifying the terminals in case the markings become obscure. This applies equally to all the cell posts, the positive being approximately $^{11}\!/_{16}$ in. and the negative $^{5}\!/_{8}$ in., small diameter, respectively. This construction aids in properly connecting the adjacent cells in series and, with cable terminals of different sizes, avoids the possibility of connecting the battery in the car with reversed polarity. In addition, the terminals usually carry the markings "+," "P," or "Pos." on the positive and "−," "N," or "Neg." on the negative, respectively, in accordance with the way the battery gives out current. The current leaves at the positive terminal.

225. Action of the Lead-acid Storage Cell on Discharge.—When a lead-acid storage cell is fully charged, the active material in the plates is in the form of lead peroxide in the positive, brown in color, and pure metallic sponge lead in the negative, gray in color. Also the electrolyte is of maximum density, having a normal specific gravity of 1.280 to 1.300. It will also be found that the voltage of the cell on open circuit is 2.1 to 2.2 volts, varying slightly with the temperature. Thus, if the cell terminals are connected through an electric circuit, such as the ignition system, lighting system, or starting motor, current will flow, due to this voltage. The current leaves by the positive terminal.

As the cell discharges, chemical action takes place between the sulphuric acid in the electrolyte and the lead compounds in the plates, changing the lead peroxide of the positive plates and the pure metallic sponge lead in the negative plates into sulphate of lead. The specific gravity or density of the remaining liquid decreases in proportion to the amount of acid absorbed by the plates. Also, the hydrogen and the oxygen liberated at the plates combine, forming water, thus further diluting the electro-

lyte. Furthermore, the lead sulphate is of larger volume than the active material, making the plates thicker, thus crowding the separators. Thus, as the discharge progresses, the electrolyte becomes weaker and weaker and the active material, converted into lead sulphate, expands in volume to such an extent that eventually the free circulation of the acid is retarded. This prevents the acid from reaching the active material fast enough to maintain the normal rate of chemical action and the voltage decreases. In fact, the voltage will drop from 2.1 to 2.2 volts (for a fully charged cell) down to approximately 1.7 to 1.8 volts when the cell is completely discharged. When it is completely discharged, practically all the active material has been converted into lead sulphate and the electrolyte, due to the loss of the acid, will have a density of very little more than pure water, namely, 1.150 or less.

226. Action of the Lead-acid Storage Cell on Charge.—The action of the lead-acid storage cell on charge consists of a reversal of the process which takes place when the cell discharges. This action is produced by sending through the cell a direct current opposite in direction to the current flow when the cell discharges; namely, *in* at the positive terminal and *out* at the negative terminal. When the charging current is sent through the cell, the action is as follows: The sulphuric acid which was absorbed by the plates during discharge is driven back into the electrolyte, thus raising the specific gravity. At the same time, the lead sulphate on both plates is converted back to peroxide of lead in the positive plates and into spongy metallic lead in the negative plates. When practically all of the acid has been transferred from the plates to the electrolyte and the sulphate converted back into its original form of lead peroxide and sponge lead, the cell is said to be fully charged and should show a specific gravity of 1.280 to 1.300 and a voltage of about 2.1 volts or more on open circuit.

When the cells are completely charged, the charging current can no longer do useful work. Its only effect will be to convert particles of water in the electrolyte to hydrogen and oxygen, which will bubble up violently, indicating that the battery is in a full state of charge.

227. Chemical Reactions in the Storage Cell.—A more thorough understanding of just what takes place in the storage cell

may be obtained by a study of the chemical reactions. The electrolyte is composed of sulphuric acid and water, chemically written H_2SO_4 for the acid, and H_2O for the water. The H_2 of the acid represents two parts of hydrogen gas, while the SO_4 represents one part of sulphur and four parts of oxygen gas and is referred to later as *sulphion.* For water, the H_2 represents two parts of hydrogen and the O one part of oxygen.

Cell on Discharge and Charge.—The chemical action which occurs in the cell on discharge and charge may be written in the form of chemical equations as follows:

Action at Positive Plate—Cell Discharging.—$PbO_2 + H_2 + H_2SO_4$ produces $PbSO_4 + 2H_2O$; that is, lead peroxide plus hydrogen plus sulphuric acid produces lead sulphate plus water.

Action at Negative Plate—Cell Discharging.—$Pb + SO_4$ produces $PbSO_4$; that is, lead plus sulphion produces lead sulphate.

Action at Positive Plate—Cell Charging.—$PbSO_4 + H_2O + O$ produces $PbO_2 + H_2SO_4$; that is, lead sulphate plus water plus oxygen produces lead peroxide plus sulphuric acid.

Action at Negative Plate—Cell Charging.—$PbSO_4 + H_2$ produces $Pb + H_2SO_4$; that is, lead sulphate plus hydrogen produces lead plus sulphuric acid.

228. Sulphation.—From the foregoing it is evident that the formation of lead sulphate ($PbSO_4$), often referred to as *sulphation,* is a normal process which makes the production of electrical energy possible. In its normal state, the lead sulphate is fairly soft and light gray in color. However, if the plates are left in a discharged sulphated condition for any length of time, the sulphate gradually hardens into a white crystalline formation having a high electrical resistance, thus tending to cover the surface of the plate with an insulating coat, rendering it partly or entirely inactive. It is this form of *abnormal sulphation* which is so harmful to a battery, since it reduces battery capacity and is the direct cause of many other troubles. Abnormal sulphation is generally caused by undercharging; therefore, it can be prevented only by sufficient charging of the battery.

229. Heat Formed on Charge and Discharge.—When the element is being charged or discharged the chemical reactions due to the passage of the current through the electrolyte, increased by the resistance of separators and grids, cause heat to be formed. This heat does not become injurious until the temperature rises

to about 105 deg. F., and it can rise to 110 deg. F. or even higher for brief periods without injury. It is, however, not considered advisable to charge a battery for any length of time after the temperature has risen to 105 deg. The battery should be either taken off charge until it has cooled down or the charging rate reduced.

230. Evaporation of Water.—The water in the electrolyte evaporates slowly due to the heat formed on charge and discharge and also due to the gassing on charge. The sulphuric acid, however, does not evaporate and, consequently, the solution becomes more dense. The water lost by evaporation must, therefore, be replaced by adding pure water. The amount of evaporation depends on the temperature and on the amount of work done by the battery, and is, therefore, a varying quantity. A safe rule to follow is to replace the water by adding distilled water every week in summer and every two weeks in winter, during ordinary use of the car. If the car is out of service, water should be added once every two weeks in summer and once a month in winter—but before it is given a refreshing charge. During cross-country touring it is good practice to add distilled water every 200 miles of travel, or once a day. The hydrometer syringe may be used for adding the water. Enough water should be added to keep the level of the electrolyte at all times up to the bottom of the inside cover, or 3/8 to 1/2 in. above the tops of the plates, as shown in Fig. 359. The cells should never be filled above this level as the electrolyte expands when charging, due both to the increase in temperature and to the gas bubbles which rise from the plates. The battery, if filled too full, will run over, resulting not only in loss of electrolyte, but in the eating away of the battery box. This also causes serious corrosion of the battery terminals and connectors. Discharge circuits may also result from the film of electrolyte remaining on the top of the battery and an acid-soaked case.

231. Necessity of Adding Pure Water.—Only absolutely pure water, such as distilled water, should be used in filling the battery. Distilled water is obtained by boiling water, catching the steam that comes off and condensing it. Distilled water can usually be obtained at any drug store or garage, and must be kept in an acid-proof vessel—a common way of storing it is in a glass bottle

or jug. Water which has merely been boiled should not be used. If distilled water is hard to obtain, melted artificial ice or filtered rain water which has not come into contact with iron pipes or tin roofs may be used. A common way of collecting rain water is to catch the rain directly in an earthenware jar set out after it has been raining for about 5 or 10 min. This insures that there are no impurities in the form of gases and small solid particles dissolved in the water on its journey from the clouds. The use of spring, river, hydrant, or well water should be avoided, as these are liable to contain iron or other substances detrimental to the life of the battery.

232. Effect of Battery Condition on Electrolyte Density.—As previously stated, the specific gravity of the electrolyte in a fully charged battery is between 1.280 and 1.300, while for the same battery in a discharged condition the specific gravity will be approximately 1.150 or less, a total drop in specific gravity of approximately 130 to 150 points. The rate of specific gravity or density change of the electrolyte upon discharge and charge is directly proportional to the active material converted into lead sulphate or *vice versa;* therefore, the state of charge may be readily determined by measuring the specific gravity of the electrolyte. This is true only if the strength of the solution has not been disturbed by the addition of strong acid, or other liquids to the cell (when only water should have been added) to replace evaporation. This testing may be done by using a hydrometer and noting the specific-gravity reading of each cell. The following table gives the specific gravity, the approximate cell voltages, and the freezing temperatures of the electrolyte for various conditions of charge with battery at the normal temperature of 70 deg. F.:

Specific gravity	Approximate cell voltage on open circuit	Condition of battery	Freezing point in degrees Fahrenheit
1 280 to 1 300	2 15 to 2 20	Fully charged	90 deg. below zero
1 260	2 1	Three-quarters charged	60 deg. below zero
1 215	2.0	One-half charged	20 deg. below zero
1 180	1 9	One-quarter charged	Zero
1.150 or below	1.8 or less	Completely discharged	20 deg. above zero

233. Variation of Cell Voltage during Charge and Discharge.—The voltage set up between plates of lead peroxide and spongy metallic lead submerged in dilute sulphuric acid will increase or decrease with the concentration (or strength) of the acid, since this affects the chemical activity. Thus, the voltage of the cell will be greatest when the cell is fully charged and on open circuit, since at this time the electrolyte is of the maximum strength. As the cell discharges and the acid decreases in concentration, the voltage will drop gradually with the fall in specific gravity. With the cell discharging, the concentration or density of the acid in immediate contact with the active material will be lower than the average concentration of the rest of the electrolyte while, with

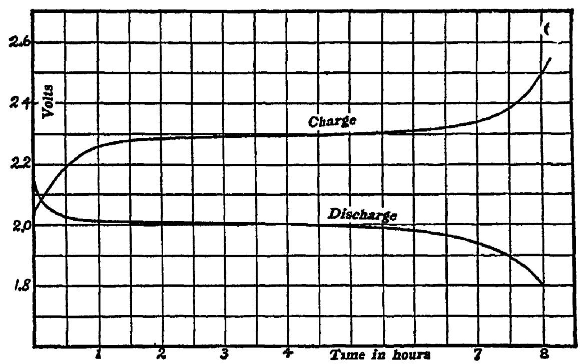


FIG. 369.—Curves showing voltage variation during charge and discharge of lead-acid storage cell.

the cell on charge, the concentration of the acid in immediate contact with the plates, especially in the pores of the active material, will be higher than the average concentration of the remaining electrolyte. Therefore, a higher voltage is required to charge a lead-acid storage cell than the cell maintains while discharging.

The variation in the terminal voltage of a lead storage cell while it is discharging at the 8-hr. rate, and also while it is being charged for the same length of time, is shown in the two curves in Fig. 369. The shapes of these charge and discharge curves depend greatly upon the thickness of the plates, the temperature of the cell, the concentration of the electrolyte, and the value of the charging or discharging current. The general characteristics, however, will be the same, the voltage per cell on discharge dropping from a maximum of 2.1 to 2.2 volts down to 1.7 to 1.8 and, on charge,

increasing from a minimum of 2.05 volts when the cell is discharged, up to approximately 2.5 volts when fully charged. To charge a cell it is, therefore, evident that the applied voltage must at least equal the maximum countervoltage produced by the cell, or 2.5 volts.

234. Capacity of the Storage Battery.—The *capacity* or amount of work a battery can do on discharge depends upon the total number of pounds of active material available for conversion into lead sulphate. This capacity is measured in *ampere-hours*, and is determined by multiplying the discharge rate of the battery in amperes by the number of hours during which the battery is capable of discharging at a given rate. Battery capacity is usually based on the discharge that can be obtained for 8 hr. A battery, for example, that will deliver 10 amp. for 8 hr. before its voltage drops too low for efficient use, say, 1.7 volts per cell, is said to have a capacity of 80 amp.-hr.

One of the inherent characteristics of a storage battery is that its total ampere-hour capacity is dependent upon the rate of discharge. The lower the rate of discharge the greater the ampere-hour capacity will be; while, on the other hand, the higher the discharge rate the lower will be the ampere-hour capacity, because at the higher discharge rates sulphate is formed so rapidly and in such bulk that the acid has difficulty in getting to the active material on the inside of the plate. Thus, a battery that has a capacity of 80 amp.-hr. at the 10-amp. discharge rate will ordinarily have a capacity of over 80 amp.-hr. at a lower discharge rate; for example, it will deliver 4 amp. for more than 20 hr. But the battery would not discharge 80 amp. for 1 hr., in fact, usually not more than about 30 min., since the efficiency of the battery drops very rapidly as the discharge rates are increased above the normal rate specified by the manufacturer. The normal discharge rating is usually to be found on the name plate of the battery.

235. Effect of Plate Area on Rate of Discharge.—There is considerable difference between the capacity of a battery and its discharge rate as stated above. The capacity is determined entirely by the total amount of active material that can be converted into lead sulphate. This naturally depends upon the thickness of the plates and the design of the grid. But, on the other hand, the total number of square inches of active plate surface determines the rate at which the battery capacity can be discharged. Thus, the design of a storage battery depends upon the service it must render. If large capacity is required, thick plates must be used; if a high discharge rate is desired, plates

of a large surface must be used, or a large number of thin plates of the same size. If thinner plates are used, more can be used in the same space, thus giving the required amount of surface for high discharge rate. In comparing two batteries from the standpoints of capacity and rate of discharge, for example, an 11-plate battery having thick plates with another battery with plates of the same length and breadth but thinner, the first battery would have the greater capacity, yet both would deliver the same discharge rate. Again, if the size of the thin-plate battery were increased to 15 thin plates, it might have the same capacity as the 11-plate battery, but it would give a greater discharge rate, due to the increased plate surface.

The porosity of the active material in the plates also affects the discharge rate. If the plate is soft and porous, it will usually take up the acid faster and give a higher discharge rate. Conversely, if the plate material is hard and comparatively non-porous, chemical action is slower and the plate will have a lower discharge rate. The hard plate, however, will usually have the longer life, as the active material will not free itself from the plate, due to the gassing produced during charge, as readily as it will from the soft plate.

236. Sizes of Battery Plates.—In order to furnish starting and lighting batteries with various capacities and discharge rates, three sizes of battery plates have been adopted to obtain the desired discharge requirements. The type of plate, its symbol, and dimensions are as follows:

Symbol	Type of Plate	Dimensions
S	Small	4¼ in. high by 5⅝ in. wide
M	Medium	4¾ to 5¼ in. high by 5⅝ in. wide
B	Large	6 in. high by 5⅝ in. wide

Each size of plate is also furnished in three thicknesses, in accordance with the battery capacity desired, namely:

T	Thin	3/32 in. thick
R	Regular	⅛ in. thick
TT	Thick	5/32 in. thick

From the above it will be noted that all plates are of the same width, the difference being in the height and thickness.

237. Internal Cell Resistance.—The internal resistance of the storage-battery cell is usually very low and in most cases can be neglected entirely in comparison with the rest of the circuit in which the battery may be connected. However, when the

battery is used for service requiring high discharge rates, such as operating a starting motor, the resistance of the external or motor circuit is so low that the little internal resistance offered by the battery becomes an important factor. Internal battery resistance is due to several factors, such as: (1) the strength and the temperature of the electrolyte; (2) the kind and porosity of the separators; (3) the resistance of the grid and the bond between it and the active material; (4) the condition of the active material, which varies widely from full charge to discharge because sulphate is a poor conductor; and (5) the number of parallel plates used in the positive and negative groups. Harmful resistance may also result, due to improper burning of the plates to the post straps and to poor connection of the top connectors and terminals.

The resistance of the battery, therefore, may vary considerably—in fact, when completely discharged, its internal resistance may be several times what it is when fully charged. In automobile starting batteries, for example, the internal resistances may be 0.015 to 0.020 ohms when fully charged and 0.050 to 0.080 ohms or over when completely discharged. The battery cells offer a comparatively high resistance when discharged because the active material has been converted into lead sulphate—a poor conductor—and the electrolyte is very little more than pure water—also a poor conductor. As the battery becomes recharged, however, the internal resistance will gradually decrease, due to: (1) the converting of the lead sulphate back into lead peroxide and sponge metallic lead; and (2) to the increased specific gravity of the electrolyte. The resistance will decrease until the cells are a little better than half charged, when it will again increase slightly as the battery rises to a fully charged condition. The resistance of dilute sulphuric acid is a minimum at a specific gravity of 1.220 to 1.240 and increases as the specific gravity rises above or falls below this value.

238. To Determine Internal Resistance of Storage Battery.—The resistance of any direct-current circuit may be calculated by Ohm's law, which is represented by the formula $I = \frac{E}{R}$, in which I = current in amperes, E = voltage in volts, and R = resistance in ohms. By transposing this formula, it may be expressed $R = \frac{E}{I}$, which is a more convenient form for calculating resistance.

Practically the same method that is used for determining the resistance of any ordinary metal conductor, namely, dividing the applied voltage in volts by the current flowing in amperes, may be

used in measuring the internal resistance of a storage cell. The process is not quite as simple, however, owing to the constantly changing conditions in the battery cell, such as temperature, condition of charge, charge and discharge rates, age of plates, level of electrolyte, etc. It is, therefore, meaningless to say that a battery has a certain internal resistance unless the condition of charge, rate of charge or discharge, temperature, etc. is definitely specified.

A fairly reliable method of determining the internal resistance of a storage cell—at least sufficiently accurate for ordinary practical purposes—is as follows: Place the battery on charge at a definite rate, say 5 amp., and note the applied cell voltage, using a sensitive voltmeter connected across the cell terminals. A voltmeter with a scale 0 to 3 volts with graduations of two-hundredths of a volt or less, such as is often used in the cadmium testing of batteries, should be used. After the cell has been on charge at the above rate for several minutes, and the highest cell voltage as indicated by the voltmeter noted, then, without disturbing the voltmeter connections, open the charging switch and note the maximum voltage reading of the cell on open circuit. The voltage will be slightly lower than the applied voltage, usually 0.01 to 0.06 volt less per cell, and represents the countervoltage set up by the cell which opposes the applied charging voltage. The difference between the charging voltage and the maximum countervoltage will be the actual voltage required to overcome the internal resistance and cause the 5-amp. charging current to flow through the cell. The internal resistance may then be readily calculated from the formula:

$$R = \frac{E - e}{I}, \tag{14}$$

in which R = internal resistance in ohms; E = applied charging voltage across cell terminals in volts; e = open circuit or true countervoltage of the cell in volts; and I = charging current in amperes. If, for example, the applied charging voltage E of a certain storage cell is 2.38 volts when charging at 5 amp., and the maximum countervoltage e is 2.32 volts, the internal cell resistance will be

$$R = \frac{E - e}{I} = \frac{2.38 - 2.32}{5} = \frac{0.06}{5} = 0.012 \text{ ohms.}$$

The total internal resistance of a complete battery of any number of cells connected in series will be the added resistances of the individual cells. The resistance of the entire battery may also be determined directly by using the above method, provided a voltmeter of suitable range and accuracy is available for measuring the higher voltages.

Note.—The results obtained by the above method are only approximate, particularly at higher charging rates, since the degree of gas formation on the plate surfaces varies with the charging rate and the condition of charge, which affects materially the observed resistance. The method, however, is usually accurate enough for the comparison of batteries operating under similar conditions.

239. Battery Efficiency.—The energy efficiency of a storage battery is similar to that of any device, namely, the ratio of the energy delivered by the battery during discharge to the energy delivered to the battery during charge. The efficiency may be determined by comparing the battery output and input either in ampere-hours or in watt-hours. The ampere-hour efficiency may be calculated as follows:

$$\text{Efficiency} = \frac{\text{Ampere-hours (output)}}{\text{Ampere-hours (input)}} \qquad (15)$$

The watt-hour efficiency is calculated in the same way, but it will usually be less than the ampere-hour efficiency, duc to the marked differences in cell voltages on charge and discharge. The efficiency will vary considerably, depending on the rate of discharge, condition of plates, temperature, internal resistance, and conditions of use; that is, if discharge is continuous or intermittent. The efficiency of the average lead-acid cell, when in good condition, is about 80 to 85 per cent at normal temperatures and discharge rates. Thus, if 100 amp.-hr. are required to charge a battery, only 80 to 85 amp.-hr. can be discharged from it. At lower temperatures, however, and at discharge rates higher than normal, the efficiency drops rapidly and may be less than 50 per cent in extreme cases. This accounts for the noticeable decrease in the efficiency of automobile starting batteries during the winter—when they sometimes require 20 to 50 per cent more charging than in summer to keep them fully charged.

SECTION XIV

STORAGE-BATTERY CHARGING AND TESTING

240. Storage-battery Testing.—Because of the action which takes place in each cell of a battery upon discharge and charge (namely, the active material combining with the acid of the electrolyte to form lead sulphate on discharge and back again to its original form on charge), the specific gravity or density of the electrolyte will change in the same proportion in which the active material changes. Thus, the testing of the specific gravity of the electrolyte provides a ready means of determining the state of charge of the battery cells. The voltage also varies in proportion to the state of charge as outlined in Art. 233. Therefore, the battery condition may also be determined by testing the voltage of each cell on open circuit and on discharge and comparing the indications with those obtained by measuring the specific gravity. Very often both tests are necessary to determine the exact battery condition, especially if acid or other liquids have been added to the cells by someone unfamiliar with batteries (usually in an attempt to charge it or prevent freezing), thereby disturbing the specific-gravity and voltage readings. The cadmium test, Art. 257, Sec. XIV, is also a reliable method.

241. The Hydrometer.—A convenient way of testing the specific gravity of the electrolyte is by the hydrometer syringe, shown in Fig. 370*A*. This instrument consists of a large glass-tube syringe containing a small hydrometer float, consisting of a graduated glass cylinder closed at both ends and weighted at the bottom so that it will float in an upright position when the tube is filled with liquid. The upper end of the float is graduated from 1.100 to 1.300 to indicate specific gravity. The rubber bulb at the top is used to draw the liquid into the syringe tube. Normally, the hydrometer float rests on the bottom of the tube, but, as soon as a liquid with specific gravity greater than 1.100 is drawn into the syringe, the hydrometer rises and floats in the liquid at a depth

depending upon the specific gravity of the liquid. With the float riding freely in the liquid as shown in Fig. 370*B*—and not clinging to the side of the syringe tube due to moisture—the scale graduation which is on a line with the surface of the liquid is the reading of the liquid's specific gravity. For convenience, the readings are referred to as being *eleven-fifty*, *twelve-hundred*, *twelve-eighty*, *thirteen-hundred*, etc., instead of 1.150, 1.200, 1.280, and 1.300, which are, of course, correct.

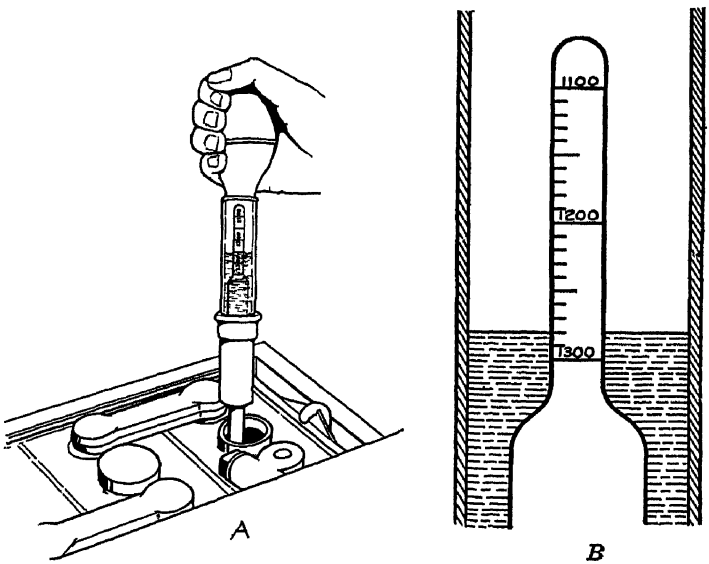


FIG. 370.—The syringe-hydrometer for testing specific gravity of battery solution.

242. Hydrometer Readings and Their Indications.—By comparing the readings obtained by the hydrometer with the table, page 318, the condition of charge of each cell can be readily determined. To simplify the taking of the readings as much as possible, red lines or other colored markings are usually placed on the graduated scale of the hydrometer float to indicate the most important specific gravity readings of 1.280, 1.215, and 1.150, which signify conditions of full charge, half charge, and complete discharge, respectively.

Each cell of a battery in automobile service should be tested regularly. A convenient time is when adding water; but the reading should be taken before rather than after adding the water,

as a reliable specific-gravity test cannot be made after the water has been added and before it has thoroughly mixed with the electrolyte, the mixing being brought about by charging or discharging the battery. Water is lighter than the acid and will tend to remain on the top. The water will usually be mixed thoroughly with the electrolyte after charging at the normal rate for about 15 min. After testing, the electrolyte must always be returned to the cell from which it was drawn and the vent plugs replaced tightly in position.

When all cells are in good condition the specific gravity should test about the same or at least within 25 points in each cell. A gravity of 1.230 indicates that the battery is over half charged, while a gravity of under 1.215 indicates that the battery is less than half charged. When a battery in service is found to be in this condition it should be used sparingly until the generator on the car restores it to at least 1.220 specific gravity. A gravity of 1.150 or below indicates that the battery is completely discharged or "run down" and it should be recharged at once to prevent abnormal sulphation.

A discharged battery is always the result of inadequate charging or a waste of current. If, after having been fully charged, the battery soon runs down again, there is usually trouble somewhere else in the electrical system.

Putting acid or electrolyte into the cells to bring up the specific gravity can do no good, and may do great injury to the plates and separators. Extra strong electrolyte is indicated by the specific gravity's rising above 1.300 on charge. Acid or electrolyte should never be put into the battery except to replace loss through spilling, and then only by an experienced battery man.

243. Variations in Specific Gravity of Cells.—If the specific gravity in any cell tests more than 25 points lower than the other cells in the battery, it is an indication that this cell is out of order. Several readings should be taken and the average determined, as the readings may vary slightly. Variations in the readings of different cells may be due to several causes, such as short circuits inside one or more of the cells; the putting of too much water in certain cells, causing the electrolyte to overflow and resulting in lowering of the density; and the loss of electrolyte due to a cracked or leaky jar.

Low specific gravity in one or more cells can often be increased by continuous driving of the car, using the starter and the lights sparingly, or by charging the battery from the generator with the engine running idle. However, if the specific gravity in one particular cell does not increase to at least 1.260

after the other cell readings indicate that they are fully charged, it is an indication that the low cell is in need of internal adjustment, such as new separators, removal of high sediment, replacement of cracked jar, etc

244. Effect of Temperature on Hydrometer Readings.—All the definite figures in hydrometer readings are based on the normal temperature of 70 deg. F. for the electrolyte. This figure refers to the temperature of the liquid itself, and not to the temperature of the surrounding atmosphere. The weather may be freezing cold, and yet the temperature of the liquid solution in the battery may be normal or above, due either to the heat of the engine or because the battery is being vigorously charged. The density of the liquid varies considerably with the temperature, being proportionately less at temperatures above 70 deg. and greater at temperatures below 70 deg. Thus, at high and low temperatures, the observed hydrometer reading will not indicate the true condition of the battery; consequently, if its true condition is desired, temperature corrections must be made.

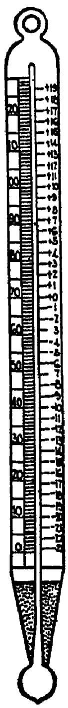


FIG. 371.—Battery thermometer.

The temperature of a battery may be readily measured with either a dairy thermometer or a special inexpensive one intended for battery purposes, as shown in Fig. 371. The thermometer is inserted through the vent-plug hole into the liquid in the same way as the hydrometer syringe tube.

The highest reading will indicate the temperature of the electrolyte. The rule in making temperature correction is that, *for every* 3 *deg. above* 70 *deg. F.*, 0.001 *be added to the hydrometer reading; and for every* 3 *deg. below* 70 *deg. F.*, 0.001 *be subtracted from the observed reading.* For example, if the temperature at the end of charge is 120 deg. F. and the observed gravity reading is 1.260, indicating three-fourths charged, the corrected reading is determined as follows:

$$120 \text{ deg.} - 70 \text{ deg.} = 50 \text{ deg.}$$
$$50 \div 3 = 17 \text{ (approximately)}$$
$$17 \times 0.001 = 0.017 \text{ (hydrometer correction).}$$

Corrected reading: 1.260 + 0.017 = 1.277, indicating almost fully charged. Again, if the reading at zero is 1.210, indicating that the battery is approximately half charged, then the true condition may be found as follows:

$$70 \text{ deg} - 0 \text{ deg.} = 70 \text{ deg.}$$
$$70 \div 3 = 23 \text{ (approximately)}$$
$$23 \times 0.001 = 0.023 \text{ (hydrometer correction).}$$

Corrected reading: $1.210 - 0.023 = 1.187$, indicating one-fourth charged.

From the above it is evident that for accuracy in testing, the difference in temperature should be corrected for. This is particularly necessary in the case of a battery that has been giving trouble.

245. Battery Charging.—Three conditions must be fulfilled in order to charge batteries successfully:

1. Direct current must be used to produce the proper electrochemical effect in the cells. If alternating current only is available, some device for converting or *rectifying* it to direct current is necessary.
2. The polarity of the charging wires must be definitely determined and the positive wire connected to the positive battery terminal and the negative wire connected to the negative terminal. This is to insure the charging current passing through the cells in the proper direction.
3. Except in very special cases, a resistance or regulating device must be used to regulate the charging rate to avoid injury to the battery.

Charging On and Off the Car.—In automobile service the starting and lighting battery is kept charged by a low-voltage D.C. generator driven by the engine. The required voltage of the generator is 7 to 8 volts for a 6-volt battery and 14 to 16 volts for a 12-volt battery. The charging rate should be sufficient to keep the battery over three-fourths charged at all times. If it does not, and the battery gradually becomes discharged, trouble exists, due either to insufficient charging or to excessive load on the battery, and it should be corrected at once. If the battery has been left in a discharged condition for any length of time, it will usually be difficult for the generator on the car to bring it up to a full state of charge. It will, therefore, be advisable to remove the battery from the car and to give it a refreshing charge from a separate source.

246. Charging from 110-volt D.C. Lines.—A common procedure when 110-volt D.C. current is available, and several batteries are to be charged at one time, is to connect the batteries in series and in circuit with suitable resistance, such as a lamp bank or rheostat, as shown in Figs. 372 and 373. When a lamp bank is used to regulate the rate of current flow, as in Fig. 372, 110-volt carbon-filament lamps of 16- to 32-cp. size should be used. The carbon lamp is preferable to the Mazda type, as it offers more resistance and is much cheaper. Each 16- and 32-cp. carbon lamp consumes 50 and 100 watts (or ½ and 1 amp.) respectively when operating on 110 volts. Consequently, if the lamps are connected in parallel with each other and the combination

connected in series with the batteries to be charged, as shown, the charging current will be controlled by the size and number of lamps connected in the circuit. The charging rate may be adjusted by turning the lights "off" or "on," or, if a rheostat is

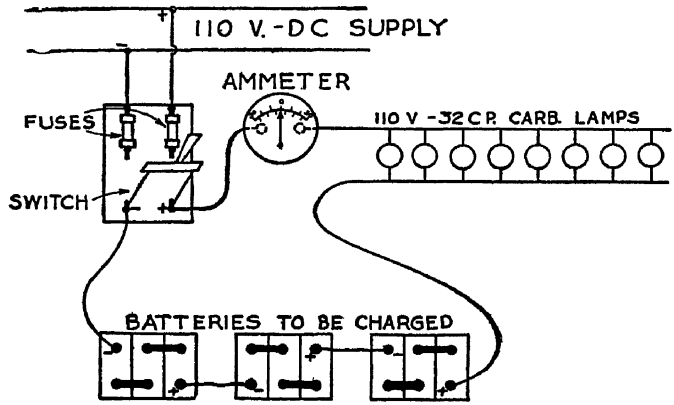


FIG. 372.—Charging batteries from 110-volt D.C. supply, using lamps for resistance.

used, by moving the handle so as to cut resistance in or out of the circuit until the ammeter shows the proper reading.

Where more than one battery is to be charged at a time, the batteries should be connected in series, that is, the positive terminal of one battery

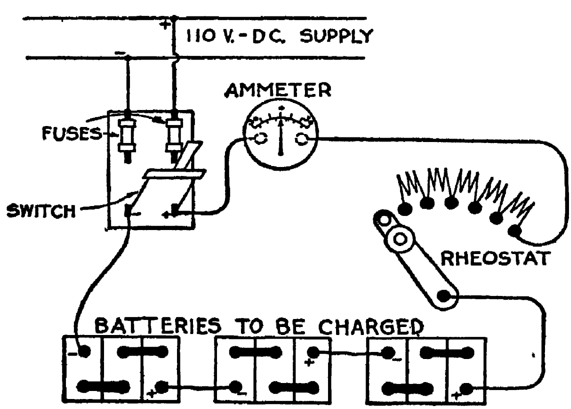


FIG. 373.—Charging batteries from 110-volt D.C. supply using rheostat for resistance.

should be connected to the negative terminal of the adjoining battery. Rubber-covered copper wire (No. 14 or larger) cut in lengths of about 18 in. should be used to connect the batteries. The wire should be connected

to the terminals either by attaching clips to the ends or by twisting the wire around the terminals. Care should be taken to see that a good contact is made without damaging the terminals.

247. Determining Polarity of Charging Lines.—Several simple methods are available for determining the polarity of the charging wires and battery terminals. One of the quickest ways is to use a high-reading voltmeter of at least sufficient range to measure the charging line voltage. A movement of the needle across the scale (usually from left to right) will not only indicate the voltage of the line but will also indicate that the positive wire is connected to the positive terminal of the meter.

If a low-reading voltmeter is the only kind available, it may be used to determine the charging line polarity as follows:

Test the cell voltage of the battery first on open circuit, then again after it is placed on charge. If the voltage on charge is higher than on open circuit, the battery is properly connected and is being charged. But if the voltage on charge is lower than the open-circuit voltage, the battery is connected with wrong polarity—is discharging—and must be reversed in order to be charged.

If a voltmeter is not available, the polarity may be determined by dipping the ends of the charging wires into a glass of water to which a few drops of acid or a little salt has been added, whereupon gas bubbles will form, chiefly around the negative wire.

It is important that the battery be properly connected for charging. If the current passes through it in the opposite direction to that necessary to charge it, the plates will eventually change their polarity, the positive plates converting into negatives and the negatives into positives. This reversal of plates usually ruins them.

248. Charging Voltages.—In charging batteries the required voltage is approximately 2.5 volts per cell, or a total of 7.5 volts for a 6-volt battery and 15 volts for a 12-volt battery. The charging voltage, however, will vary with the charging rate and the condition of charge of the battery. Charging voltage curves are shown in Fig. 369.

If several batteries are to be charged in series, the total voltage required to charge them may be figured on the basis of 7½ volts for each 6-volt battery, or 2½ volts per cell. On a 110-volt D.C. circuit, the maximum number of 6-volt batteries that can be charged in series at one time will be 110 volts divided by 7.5,

or approximately 14. In order to permit variation of the charging rate, however, not over 10 to 12 6-volt batteries should be put on one line. Any 12-volt batteries to be charged should be counted as two of the 6-volt type. In case the total counter-voltage of the batteries should equal or exceed the operating voltage of the charging generator, little or no current will charge the batteries; in fact, should the generator voltage fall below the total battery voltage, the current will reverse in the circuit and the batteries will actually discharge back through the generator. Thus, care should be taken not to overload the charging line; also that the charging rate does not exceed the maximum rate of the battery in the line requiring the lowest charging current.

249. Charging Rates.—The proper charging rate for a battery depends upon the size, condition, and number of plates in each cell as well as upon the condition of charge. The normal charging rates of most batteries are marked on the name plate on the side or end of the case. Two rates, *start* and *finish*, are usually given. The start rate is intended for the battery when it is well discharged, yet in a healthy condition, while the finish rate—approximately one-half the start rate—is the recommended rate for the battery after it is over half charged and is approaching a full state of charge. The charging rate is reduced to prevent excessive heating, gassing, and evaporation of the electrolyte.

If the charging rates are not marked on the battery, they may be determined roughly if the ampere-hour capacity of the battery is known. A safe charging rate at *start* for starting- and lighting-type batteries is one-eighth of the ampere-hour capacity rating, and the finish rate one-half of the normal starting rate. For example, if it is known that a battery is of the 80-amp.-hr. capacity size, the charging rate to start will be one-eighth of 80, or 10 amp. and the finish rate will be 4 amp. (The ampere-hour capacity of a battery may be figured by multiplying the normal discharge rate by the number of hours as given on the name plate.)

Another method of determining the *start* rate, if the number of plates in one cell is known, is to allow 2 amp. for each positive plate. Thus, for a thirteen-plate battery which has six positive

plates per cell, a safe charging rate will be 6 × 2, or 12 amp. In like manner, the charging rates for seven-, nine-, eleven-, and fifteen-plate batteries, either 6- or 12-volt, will be 6, 8, 10, and 14 amp. respectively. In all cases the finish rate will be approximately one-half of the start rate.

If neither the ampere-hour capacity nor the number of plates in the cell are known, the charging rate at the start may be taken as 10 to 12 amp., but it should be reduced to a lower rate if any of the cells show signs of excessive heating or gassing. The temperature of the cells should be watched closely, and, should it exceed 110 deg F., the charging should either be stopped until the battery cools or the charging rate reduced.

250. Procedure in Battery Charging.—The usual procedure in charging batteries that have been in service is as follows: Before placing the battery on charge, and before the vent plugs (or caps) are removed, the entire top of the battery should be thoroughly cleaned, either by wiping with a wet rag or sponge or by flushing with clear water from a hose and then wiping dry. This is to prevent any dirt or impurities from falling into the cells; and also to avoid current leakage over the tops of the cells. If any of the connectors or terminals are corroded, the corrosion should be cleaned off, using a solution of ordinary baking soda and water to counteract the action of the acid. The vent plugs are then removed and distilled water added to each cell until the level of the electrolyte stands approximately 3/8 in. above the tops of the separators. The plugs are then usually put back in place to prevent flooding during charge, and the battery connected with proper polarity into the charging circuit. The plugs should only be removed for inspection of the cells and hydrometer testing. If the battery is in a fairly healthy condition—merely discharged—it should be charged at the start rate until gassing begins vigorously in one or more cells, when the charge rate should be reduced to the finish rate. If the battery is known to be badly sulphated, it should be charged from the beginning at a lower rate—usually the finish rate—otherwise it may over-heat. The lower rate is also better for breaking up abnormal sulphation.

After charging for several hours, gas bubbles will appear on the surface of the electrolyte. This is known as "gassing" and should

take place in each cell as it approaches a charged condition. Continuous gassing, however, is usually accompanied by a rise in temperature and a rapid evaporation of the electrolyte, so that the frequent addition of water will be necessary. The gassing also has a deteriorating effect on the plates, since the releasing of the gas bubbles on the plate surface tends to liberate particles of the active material, which will then fall to the bottom of the cell as sediment and cause a loss of plate capacity. Thus, when any cell begins to over-heat or gas vigorously—and the voltage of each cell is 2.4 volts or more—the charging rate should be reduced to prevent injury.

Hydrometer readings should be taken at least three times a day during charging, and distilled water added as needed at the same time, but only after readings have been taken. All cells should be plentifully supplied with water, but not with so much that the solution overflows when gassing, as the electrolyte will naturally expand when filled with gas bubbles and when the temperature rises. It is also advisable to test the cell voltages occasionally with a low-reading voltmeter as a check on the hydrometer indications.

To Determine If Battery Is Fully Charged.—A battery is fully charged when, with the current flowing at the finish rate, all cells are gassing vigorously and the specific gravity and the voltage show no increase over 3 to 5 hr. of continuous charging. The specific gravity for batteries used in temperate climates should show a specific gravity of 1.280 to 1 300 in each cell. The voltage will read 2.4 or higher per cell while charging, but will drop to about 2.25 immediately upon removing the battery from charge, after which it will gradually drop to 2.1 to 2 2 volts per cell. The voltage, however, will vary slightly with the temperature.

Electrolyte Density for Batteries in Warm Climates.—In climates where the average temperature is around 90 deg. F. or more, or where water does not freeze throughout the year, a lower specific gravity for a fully charged battery is recommended, namely, about 1.250 instead of 1.280. This also applies to batteries used for farm-lighting and power purposes. This specific gravity reduces the maximum concentration of the acid, which has a deteriorating effect upon the active material and the grids, thereby increasing the life of the plates.

Taking Battery Off Charge.—When the battery is completely charged, it should be disconnected from the circuit and the vent plugs removed to permit the escape of any gas that may have

accumulated in the tops of the cells during charge. This gas is a combination of oxygen and hydrogen and is very explosive; therefore, care should be taken not to allow a spark or an open flame to come close to the vent-plug hole. After proper ventilation and filling of the cells with distilled water to the proper level, the vent plugs should be screwed tightly in position. The tops of the cells and the terminals should again be cleaned thoroughly to remove any spilled water or electrolyte and the terminals given a light coat of vaseline to prevent corrosion. The battery is then ready for service.

251. Balancing Cells to Proper Specific Gravity.—When the battery is fully charged the electrolyte should test within 10 points in all cells. If it does not, an adjustment of the gravity of the electrolyte, known as *balancing the cells,* is necessary. This will be necessary also if the specific gravity goes over 1.300 or below 1.280 when fully charged. Excessive gravity would indicate that acid had been added when only water should have been used to replace evaporation, while low specific gravity indicates loss through spilling, due either to a cracked jar or to over-filling. The specific gravity may be corrected, if too high, by removing some of the electrolyte from the defective cell and replacing with a like amount of distilled water, then charging and repeating the operation until the proper specific gravity is obtained. In case the specific gravity is too low, it may be increased to the proper gravity by removing some of the electrolyte and replacing with a like amount of electrolyte of 1.350 or 1.400 specific gravity, then charging and repeating the adjustment until the proper gravity is obtained.

Caution—In adjusting the specific gravity, acid stronger than 1 400 should never be added to a battery, as it will cause injury to the plates and separators

252. Mixing Electrolyte.—In preparing electrolyte for the lead-acid battery only chemically pure sulphuric acid (H_2SO_4), having 1.835 specific gravity and distilled water should be used. The proper proportions of acid and water by volume and weight which will give the desired specific gravity at normal temperatures are as follows:

TABLE OF PROPORTIONS FOR MIXING ELECTROLYTE

Specific gravity of solution (70 deg. F.)	Parts of water to one part c.p. sulphuric acid of 1.835 specific gravity at 70 deg. F.		Percentage of sulphuric acid in solution
	By volume	By weight	
1 120	8 0	4 4	17.4
1 150	6.15	3 35	21 4
1 180	4.95	2 7	25 2
1 200	4 33	2 36	27.7
1 220	3 84	2 09	30 2
1.250	3 22	1.76	33.7
1 270	2 9	1.57	36 1
1.280	2 75	1 49	37.3
1.300	2 47	1 34	39.65
1.335	2 0	1 15	42 5
1 350	1 95	1 06	45 2
1.400	1 56	0 84	50.5

In mixing the electrolyte, care should be taken to *pour the acid into the water, never water into the acid,* as this will cause the mixture to heat so violently that the solution will boil over and probably injure the operator and break the container. The mixing should be done in an acid-proof vessel, such as glass, china, earthenware, hard-rubber or lead—and never a metallic container, unless it is lead-lined. The acid should be poured slowly into the water, the solution being stirred continuously with a glass rod or clean wooden paddle so that it mixes thoroughly with the water. The electrolyte should then be allowed to cool below 90 deg. F. before putting it into the cells. It will be found that there is a slight loss in volume of the solution on account of the evaporation of the water when it unites with the acid.

253. Preparing New Batteries for Service.—The procedure in preparing a new battery for service will depend upon whether the battery was shipped from the factory in a semi-dry charged condition or "bone dry," with or without previous charging. Batteries shipped in this condition are said to be prepared for export shipment. The battery is assembled complete in every

way, including plates, separators, etc., but minus the electrolyte, which must be supplied, and the battery usually charged before it is put into service. Batteries shipped with wood separators are usually charged at the factory, then the electrolyte emptied out and the vent plugs sealed to prevent air from reaching the plates and separators, since they are in a moist condition and should not be permitted to dry out. Batteries using rubber insulators, however, such as the Willard equipped with Threaded Rubber separators, can be assembled and shipped in a "bone-dry" charged condition. These batteries are ready for service as soon as the acid of 1.285 specific gravity is added to all cells. They will require charging only if the plates were shipped in an uncharged condition.

Procedure for Charged, Unfilled Batteries Using Wood Separators.—The following instructions for the Westinghouse battery are representative of the procedure which will be required in batteries having wood separators, charged at the factory and shipped without electrolyte.

1. Remove vent plugs and discard soft rubber caps used in sealing.

2. Fill all cells with 1.300 specific gravity sulphuric acid until tops of ~~connecting~~ straps (seen through vent hole) are completely covered, using acid below 90 deg. F.

Note—Some of the acid will be absorbed by the plates and separators so that the gravity will eventually stand at about 1 285 when fully charged

3. Allow batteries to stand after filling from 2 to 3 hr. before putting on charge.

4. Put on charge at finish charge rate shown on name plate, setting vent plugs loosely on tops of holes to prevent flooding during charge.

Note—Care must be taken that the battery temperature does not exceed 110 deg F. if it does, reduce charging rate

5. Continue charging until all cells are gassing freely and individual cell voltage and specific gravity of electrolyte have shown no decided rise for a period of 5 hr.

Note—The time required to charge a new battery completely depends largely upon the length of time the battery has been in stock, varying from 12 to 24 hr. for a comparatively fresh battery to from 4 or 5 days for a battery 6 months or older.

6. Keep level of electrolyte above tops of separators at all times while charging by adding distilled water to replace that lost by evaporation.

7. After battery is completely charged, the specific gravity of the electrolyte in all cells should be adjusted to 1.285 at 70 deg. F. and the level of electrolyte adjusted so that after the battery is taken off charge the electrolyte stands ½ in. above the tops of the separators.

Note.—If the electrolyte temperature is much above or below 70 deg F, correction for temperature should be made. For method of correcting specific gravity, see Art. 244.

After making specific-gravity correction, the battery should be charged several hours to insure the proper mixing of the electrolyte and to see that the correct specific gravity of 1 285 has been obtained.

8. After the preceding instructions have been followed, examine each vent plug to see that the gas passage is not obstructed, then screw back into place. The battery is now ready for service.

Procedure for Willard Bone-dry Non-charged Batteries with Threaded-rubber Separators.—1. Remove the vent plugs and fill each cell to the top of the vent hole with electrolyte of 1.275 specific gravity, as shown in Fig. 374, making sure that it has been well mixed and is below a temperature of 90 deg. F.

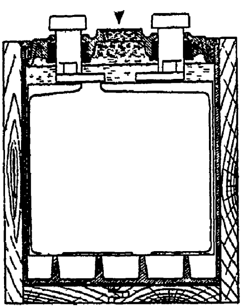


FIG. 374.—Cross section of cell showing level for the first filling of a bone dry battery.

2. After waiting 5 min., again fill each cell to the top of the vent hole with 1.275 electrolyte.

Note—The level of the electrolyte will go down, since a portion of the solution will be absorbed by the plates and separators, as they have been standing dry without any liquid in the cells.

3. Allow the battery to stand at least 12 hr., and not more than 24 hr., before charging.

Note.—After filling the cells, an increase in temperature of the electrolyte will take place, caused by the acid in the solution penetrating the plates and reacting with the active material. Since the acid in solution joins the material in the plates, the density of the solution becomes proportionately lower. This is to be expected and should cause no concern In fact, in order that all of the active material in the plates may be in chemical action during charge, the battery should stand before being placed on charge until the acid has had time to penetrate the entire thickness of the plates. This requires at least 12 hr., but should not take more than 24 hr.

4. Fill cells with 1.275 electrolyte to ⅜ in. above the tops of the separators. After this, add only distilled water as needed to maintain proper level.

5. Put battery on charge at finish rate until the gravity stops rising. At the end of this period the specific gravity should be between 1.280 and 1.300.

Note.—The time required for the above charging will vary from 36 to 72 hr Care should be taken not to prolong the charging unduly, as the excessive gassing tends to cause shedding of active material

6. Inspect each cell every few hours and add distilled water as needed to maintain the proper level of the electrolyte. Also note the temperature of the electrolyte and, if it tends to exceed 110 deg. F. reduce the charging rate.

7. If, at any time during charge, the density of the electrolyte rises above 1.300, some of the solution should immediately be drawn off with a syringe and replaced with distilled water, repeating same as often as necessary to keep the density below 1.300.

8. Continue charge until each cell is gassing vigorously and shows no increase in voltage and specific gravity for 3 to 5 hr., charging at the finish rate. The specific gravity should be balanced to read within the limits of 1.280 to 1.285 in each cell after charging.

9. When taking battery off charge, the solution should cover the tops of the separators ⅝ in. After the battery solution has had time to cool to normal temperature, draw off the excess to a final height of ⅜ in. above the separators. Replace the vent plugs and the battery is ready for service.

Preparing Non-charged, Unfilled, Wood-insulated Batteries.—The procedure in preparing non-charged, unfilled, wood-insulated batteries is similar to that for the Willard battery with threaded-rubber separators. The only difference is that the electrolyte used for filling the cells should be of 1.335 specific gravity instead of 1.275, because the wood separator absorbs more acid than does the threaded rubber. After filling, they should also be allowed to stand 10 to 15 hr. The length of time required for the initial charge should be at least 48 hr. at the finish rate.

Note.—When wood-insulated batteries are prepared, unfilled, for shipment, they should be placed in service before the date indicated on the tag attached to the battery.

254. Charging Batteries in Storage.—There are two general methods of putting a battery into storage, namely, *wet storage* and *dry storage*, the method adopted depending upon the condition of the battery and the length of time it is to be out of service.

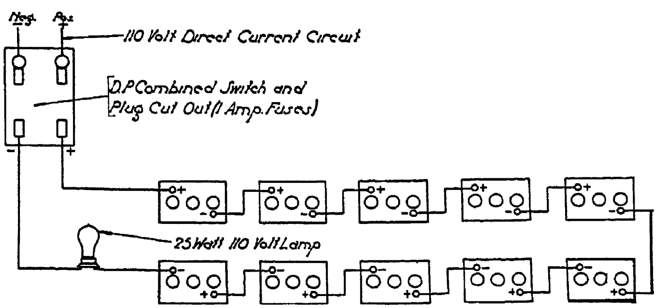


FIG 375 —Connections for giving batteries "trickle" charge

Wet Storage.—Wet storage is recommended for any battery that is to be out of service less than one year, provided it will not soon require repairs necessitating a dismantling of the cells. Wet storage consists of charging the batteries either periodically, say once a month in winter and once each two weeks in summer, at the normal charge rate, or continuously at a very low rate. The latter method is termed a "trickle" charge and in many cases will be found more convenient to arrange for than the periodic charging at a higher rate. This can be accomplished by connecting not more than fifteen three-cell batteries in series across a 110-volt D.C. circuit and in series with one lamp, as shown in Fig. 375. If only from one to ten batteries are to be taken care of, a 25-watt lamp should be used; while if there are eleven to fifteen batteries, a 40-watt lamp should be used.

The lamp will burn at reduced brilliancy and allow a current of so low a rate to pass that gassing is avoided, yet enough charge is given to maintain the batteries in good condition. Before putting on "trickle" charge and at

intervals during the charge (at least once a month) the filling plugs should be removed and water added if necessary. The specific gravity should also be tested to make sure that all cells are in good condition.

Dry Storage.—Dry storage is recommended for any battery that is to be out of service for longer than one year, regardless of its condition; also, for any battery on which repairs necessitating dismantling are, or soon will be, required. This method consists of storing the battery in a dry state, without the electrolyte, the advantage being that the plates are given a rest for the period it is in storage.

To prepare a battery for dry storage it must first be fully charged, preferably at the finish rate, until all cells are gassing freely and the specific gravity of the electrolyte and the voltage of each cell show no increase over 5 hr. of continuous charging. This process drives the acid out of the plates. The following procedure should then be followed:

1. Record the specific gravity of the battery when fully charged, to be used as a guide when putting the battery back into service.
2. With enough pure water on hand to fill the battery, remove the vent plugs and empty the electrolyte out of all cells as soon as possible after the charge is completed by upsetting the battery. Immediately replace the electrolyte with pure water. Care should be taken not to allow the battery to stand without the water, as the negative plates may become hot. The use of distilled water is unnecessary.
3. Should any electrolyte be spilled on the case, it should be wiped off with a rag moistened with ammonia or soda solution.
4. Allow the battery to stand filled with water for approximately 5 hr., then empty out the water, and take the battery apart for the inspection of plates and the removal of separators. The separators can be discarded, as they should not be used again.
5. After the plates have been flushed off with water and allowed to dry, the positive and negative groups should then be replaced in their respective cells and, with the connectors and other parts tied securely to the handles, the battery should be stored in a dry place free from dust.

To Put Battery Back into Service.—When putting a battery that has been in dry storage back into service it should be reassembled with new separators and new electrolyte, using electrolyte 0.050 points higher in specific gravity than the old electrolyte. When the old separators are put back, use the same gravity solution as the old electrolyte. After filling with electrolyte, the battery should be allowed to stand at least 10 hr., then charged at the finish rate in accordance with the procedure explained in Art. 253 for preparing for service charged, unfilled batteries having wood separators.

255. Cost of Power for Battery Charging.—The cost of the electric power consumed in battery charging is usually calculated

on the basis of so much per kilowatt-hour for the power furnished by the electric power company regardless of whether it is alternating current supplied to a rectifier, or direct current consumed directly by the batteries. This can be determined readily by multiplying the kilowatt-hours consumed by the rate per kilowatt-hour. A 6-volt battery, for example, that is charged alone on a 110-volt D.C. circuit at an average charging rate of 8 amp. and for a period of 12 hr., would consume 110 × 8, or 880 watts, or 0.88 kw., for 12 hr., or a total of 10.56 kw.-hr. If the cost of power is, say, 10 cts. per kilowatt-hour, then the total power cost will be 10.56 × 0.10, or $1.056. It is uneconomical to charge a single battery on 110 volts, since a charging voltage of 110 volts is being used when a voltage of 7½ to 8 volts is sufficient to charge a 6-volt battery. This means that only 8 volts are actually used by the battery while the remaining 102 volts are being consumed by the rheostat, or lamps used for controlling the charging current. It is, therefore, evident that a number of batteries, say eight to ten, or even thirteen, could be safely charged in series with approximately the same power cost as for the one 6-volt battery. In case ten 6-volt batteries are charged in the series, the power cost of $1.056 will be divided among ten batteries, making an individual cost of $0.105 (10½ cts.).

Thus, the power cost for charging each battery will depend upon: (1) the number of batteries charged at one time, (2) the rate paid per kilowatt-hour, and (3) the number of kilowatt-hours consumed. To the power cost should be added the cost of labor, depreciation, insurance, advertising, free service, etc., in order to obtain the exact cost of battery charging.

256. Discharge Test for Determining Battery Capacity.—Since the capacity or ability of a battery to do work is usually calculated in ampere-hours, its capacity can readily be determined by discharging the battery through a suitable resistance and multiplying the discharge rate in amperes by the number of hours the discharge is maintained from full state of charge to full discharge. The point of complete discharge should correspond to a minimum specific gravity of 1.120 and a voltage of 1.7 volts per cell.

When batteries are first put into service, either as new batteries or after being in storage, the plates will not be as active at first as they will after passing through several cycles of discharge and

charge, which opens the pores of the active material, thereby decreasing internal resistance and increasing chemical activity. The battery capacity will thus increase slightly with the first few cycles of discharge and charge; therefore, if it is desired that the battery should be in the best condition when placed in service, it should be given at least one complete cycle of discharge and charge at the normal rates, in addition to the initial charge. This is also helpful for batteries that have been revived from a badly sulphated condition by prolonged charging at a low rate.

A simple discharge device for low discharge rates can be improvised by connecting two or more headlight bulbs in parallel. The discharge rate can be controlled by choosing the proper size bulbs, using standard 6-volt bulbs for discharging three-cell batteries and 12-volt bulbs for six-cell batteries The approximate current consumption of 15-, 18-, and 21-cp. bulbs are 2½, 3, and 3½ amp., respectively. Thus, if a discharge of 9 amp. is desired, three 18-cp. bulbs may be used, while, if the discharge is to be 10 amp , two 21-cp. and one 18-cp. bulbs can be used. At normal discharge rates, the capacity of either a new or a rebuilt battery should test at least 75 per cent of its rated maximum capacity. If it does not, the plates have either lost a large proportion of their active material through shedding or are otherwise in an unhealthy condition.

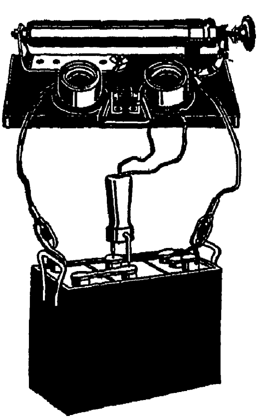


FIG. 376.—The Allen-Bradley battery discharge test device

Starting batteries should also be capable of discharging at sufficient rates to operate the starting motor without an excessive drop in voltage This may be determined by discharging the battery at comparatively high rates, such as 75, 150, and 300 amp. and noting the voltage maintained at the cell terminals. A typical discharge device for obtaining various discharge rates is shown in Fig. 376. If the battery is capable of maintaining a voltage of 1.7 volts per cell or over at the higher discharge rates, at normal temperature, it will usually give satisfactory cranking service. If it does not maintain this voltage, several troubles may exist, such as the plates being sulphated, being discharged, being worn out, having insufficient plate area, or being of unequal capacity. This may be determined by the *cadmium test*, Art. 257. There may also be excessive internal resistance or poor circulation of the electrolyte, both of which will retard the discharge rate.

257. Cadmium Testing.—The cadmium method of testing the battery is probably the most reliable method that can be used, provided it is thoroughly understood. It is even more reliable

than the hydrometer method of testing of cell voltage, as it reveals more of the real condition of the plates. By the cadmium test three principal facts can be accurately determined regarding the battery, namely: (1) if the battery is fully charged; (2) if the battery is fully discharged; and (3) if the capacity of both positive and negative plates are equal in amount. To determine the state of charge and discharge, the hydrometer can ordinarily be depended upon, provided both sets of plates are of equal capacity. It often happens, however, that when the battery is tested with the hydrometer the results show the battery to be fully charged but, when it is put in service, it will not give its full capacity, generally, because one set of plates, either positive or negative, is more or less worn out, or over-sulphated, and not capable of absorbing and holding its full charge; or, it may be that one set of plates has a lower capacity than the other. Such a condition may also be due to the battery's having been rebuilt by using new positive plates with the old negatives, which may be badly sulphated, and of less capacity, requiring more charging than the new positives. The cadmium test will definitely determine this condition.

Equipment Used in Cadmium Testing—The equipment needed to make this test consists of a set of test prods as shown in Fig 377, to one of which is attached a stick of chemically pure cadmium, and a low-reading voltmeter, such as shown in Fig. 378 The meter used should be of a high-resistance type especially designed for this purpose and having a scale of zero to 0.30 volts on one side (usually to the left of zero), which will be referred to as the negative side, and zero to 2.7 on the other side, or to the right of zero, which will be referred to as the positive side. A typical cadmium voltmeter scale

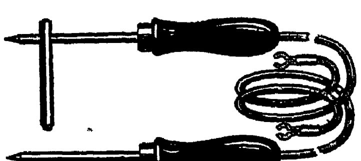


Fig. 377.—Cadmium test prods.

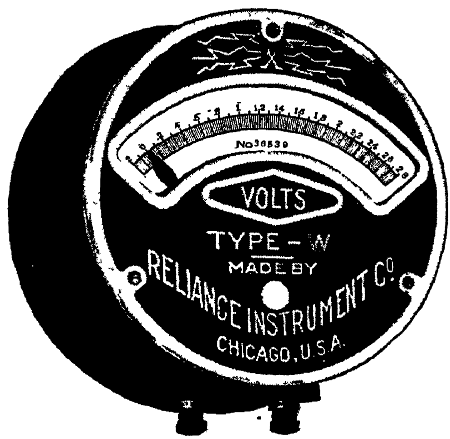


Fig. 378.—Typical Voltmeter used for cadmium testing of batteries. (*Reliance No.* 1043.)

is shown in Fig 379. As noted, the scale is divided so as to permit voltage readings down to one-hundredth of a volt.

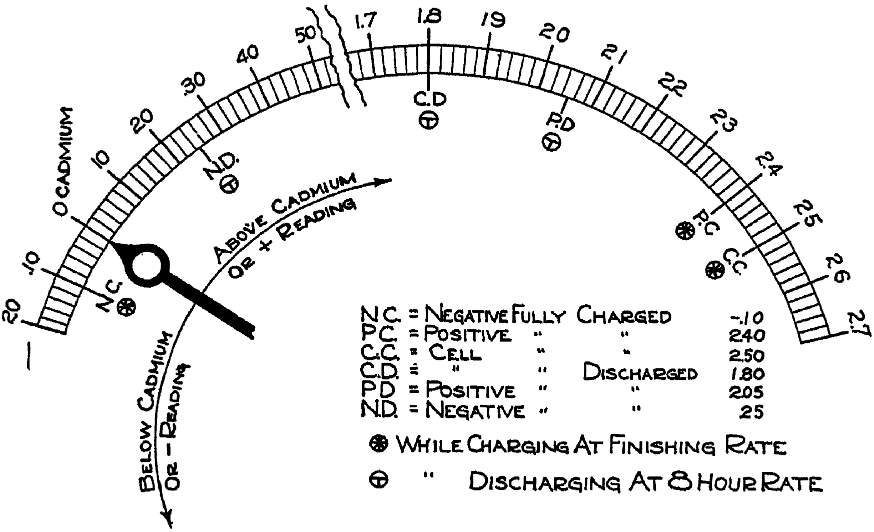


FIG. 379.—Typical scale for cadmium voltmeter indicating readings for various battery conditions.

Method of Making Test.—The cadmium test should be made only with the battery either on charge at the finish rate or on discharge at the 8-hr. discharge rate, and, if possible, at a definite temperature, preferably 80 deg. F. The connections for making the test are as shown in Fig. 380. The test prod which carries the cadmium stick is connected to the negative terminal of the voltmeter, while the plain prod is connected to the positive terminal. With the battery on charge or discharge at the rates indicated above, the cadmium stick should be inserted through the vent hole of the cell to be tested, so that it makes contact with the electrolyte. The other prod can then be used for making voltage readings between the cadmium stick and either the positive or the negative cell terminals. When it is in contact with the positive terminal, the condition of the positive plates may be determined, and when in contact with the negative terminal, the condition of the negative plates may be determined by the readings of the voltmeter.

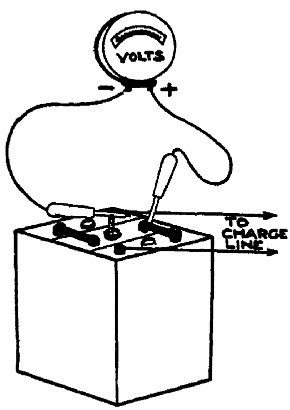


FIG. 380.—Method of making cadmium tests.

In making the tests, the cadmium must not touch the plates and separators, as improper voltage readings would be obtained. To prevent such contact, the cadmium stick should be covered with rubber tubing so perfo-

rated that the cadmium makes contact with the electrolyte, but cannot touch the plates. Another precaution is that, before any voltage readings are obtained, the cadmium stick should remain in the electrolyte for a minute or more to permit a coating of cadmium sulphate to form on the surface of the cadmium. If this is not done, the sulphate will form during the test, giving unreliable voltage readings This coating of cadmium sulphate is essential and should not be scraped off. It would be advisable to keep the stick submerged either in a solution of sulphuric acid or in pure water, if possible, to keep it from drying out.

Theory of Cadmium Test.—Cadmium is an individual metal or element just as iron, zinc, lead, etc., and, when placed in contact with a solution of sulphuric acid with some other metal, such as lead, definite voltages will be set up, due to the difference in the action of the acid on the two metals. If cadmium is used in combination with pure sponge lead (Pb), such as found in the negative plate of a battery, a voltage of approximately 0.10 volt will be produced, the cadmium being positive and the lead plate negative in polarity If the cadmium is submerged in combination with lead peroxide (PbO_2), a still different voltage will be obtained, namely, approximately 2.4 volts, and the cadmium which was formerly positive to the sponge lead plate is now negative to the lead peroxide plate. Again, if the cadmium is tested in combination with a plate of lead sulphate ($PbSO_4$), a still different voltage will be set up, the voltage depending upon the degree of sulphation. Thus, by testing the voltages between the cadmium stick and the positive terminal, and between the cadmium stick and the negative terminal, the relative conditions of the positive and negative plates may be interpreted from the readings obtained.

258. Interpretation of Cadmium Readings.—Cadmium readings should be taken only while the battery is charging at the finish rate or discharging at the normal 8-hr. rate—never on open circuit, otherwise the readings obtained would be meaningless. On charge, the voltage readings will naturally be higher than on discharge, owing to the presence of the applied voltage of the charging line; consequently, this difference must be considered in interpreting the two sets of readings.

Cadmium Readings with Battery on Charge.—With the battery on charge at the finish rate, the voltage reading between the cadmium and positive terminal should be approximately 2.4 volts to the right, or positive, side of zero, if the positive plates are fully charged while the cadmium reading for the negative plates should be 0.10 volt to the left, or negative, side of zero. The total cell voltage may then be obtained by adding the two readings, making a total voltage of approximately 2.5 volts. This should agree within 0.03 volt of the cell voltage obtained directly across the

cell terminals. If it does not, the cadmium readings are in error and should be made over. The above voltages indicate that both sets of plates are in good condition and fully charged.

If, however, a reading of 2.35 volts is obtained for the positive plates and the test for the negative plates gave a reading on the same side—to the right—of zero, say 0.10 volt, the total voltage of the cell would be obtained by subtracting the negative reading of 0.10 volt from the positive reading of 2.35 volts, giving 2.25 volts as the total voltage of the cell. Such a test would indicate that the battery is not in good condition as a whole, because the negative plates are not charged to such a condition as to give a reading to the left of zero. In other words, the negative plates do not have the same degree of charge as the positives. This may readily be the case when new positives are installed using old negatives, especially if the latter were partly sulphated when the positives were installed.

Cadmium Readings with Battery on Discharge.—With the battery on discharge at the normal 8-hr. discharge rate, the cadmium voltage readings for the positive plates should be 2.15 volts at the beginning of the discharge, remaining fairly constant the first 4 hr., then dropping to 2.05 volts when fully discharged. The cadmium readings for the negative plates at the beginning of the discharge should be +0.12 volt (on the same side of zero) and rise gradually to +0.25 volt when fully discharged. The actual cell voltage may then be determined by subtracting the negative-plate cadmium reading from the positive, giving a cell voltage of 1.8 volts. This value should check with the cell voltage taken directly across the cell terminals within 0.03 volt. These voltage readings indicate that the battery is discharged to the lowest safe limit and that further discharging would be harmful.

When testing a battery for discharge capacity, readings should be taken every hour. Should the positive cadmium reading reach 2.05 volts before the negative cadmium reaches 0.25 volt, it indicates that the positive plates either have less capacity than the negatives or that they were not fully charged in the first place. On the other hand, should the negative plates give a reading of 0.25 volt before the reading of the positive plates drops to 2.05 volts, it indicates that the negative plates either have less capacity or were not fully charged in the first place.

Under such circumstances—one set of plates showing greater capacity than the other—the capacity of the battery can only be equal to the capacity of the poorest set of plates. Such a battery will show quick drop in voltage on discharge and give poor results as to capacity. The only way the battery can be brought up to capacity is by giving it a long charge at a low rate. If it does not then, however, show the proper cadmium test, the plates are either defective or worn out and must be replaced.

From the foregoing, it is evident that, if the voltage readings are properly taken, the cadmium test forms the most accurate test that can be made to determine the true condition of the plates. This test should, therefore, be applied to all repaired or rebuilt batteries before they are placed in service. The hydrometer method of testing, however, is usually sufficiently accurate for most recharge jobs.

SECTION XV

BATTERY-CHARGING EQUIPMENT

259. Charging Batteries from Direct-current Power Lines.—The general principles of charging batteries from 110-volt D.C. supply where lamps connected in parallel, or a rheostat, are used were explained in Sec. XIV. When batteries are to be charged commercially, using lamps for resistance, the arrangement shown in Fig. 381 will be found convenient and

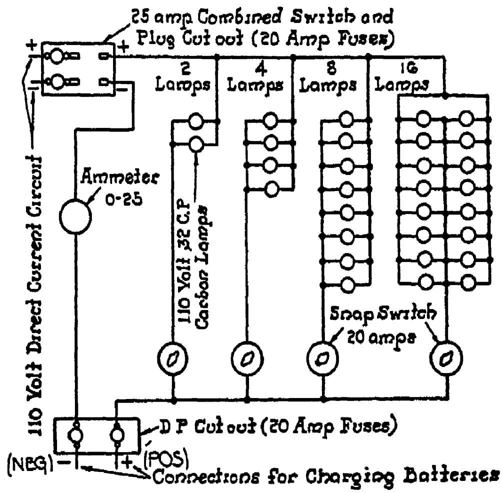


FIG. 381—Arrangement of lamps to charge batteries on 110-volt D.C. supply at different rates.

inexpensive. Thirty ordinary lamp sockets are mounted on a board and wired to snap switches in groups containing two, four, eight, and sixteen lamps, respectively. A suitable main switch, fuse cutout, ammeter, and terminal block complete the outfit.

With this equipment, from one to twelve three-cell batteries can be connected in series (the positive terminal of one connected to the negative terminal of the next and so on) and charged at one time.

The lamps which are in series with the batteries make it possible to regulate the current passing through the battery to the proper value. Different combinations of the switches permit current to pass through two, four, six, eight, and so on, up to all thirty lamps and through the batteries in series with them.

Charging from 220-volt D.C. Line.—In case charging is from a 220-volt D C. circuit, either 220-volt bulbs, arranged as in Fig. 381, or 110-volt lamps, arranged in groups of two in series, as shown in Fig. 382, can be used. If 110-volt lamps are used, the two lamps in each series group should be of the same capacity, otherwise the smaller one will be over-loaded and will burn out. A maximum of 24 three-cell batteries may be charged in one circuit on this voltage.

Charging from 550-volt D.C. Line.—When charging is to be done from 550

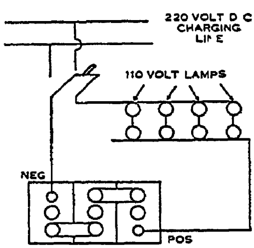


FIG. 382.—Method of connecting 110-volt lamps for charging battery on 220-volt D.C. circuit.

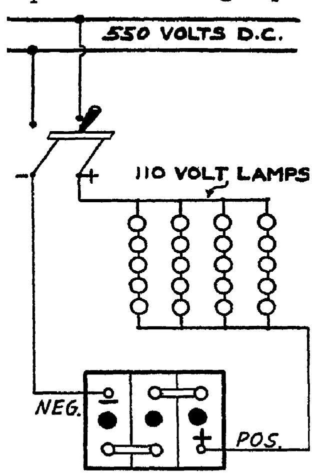


FIG. 383.—Method of connecting 110-volt lamps for charging battery on 550-volt D.C. circuit.

volts D.C., that commonly supplied for street-railway power service, the arrangement of lamps will be similar to the arrangement given for 220-volt service, except that five 110-volt lamps are connected in each series group, as shown in Fig. 383. Charging at this voltage is not to be recommended unless at least 30 three-cell batteries are to be charged at one time, because of the high cost of charging per battery and because it is dangerous to work with such high voltage. High voltage should, therefore, be used only in emergency or in case a large volume of batteries is to be charged at one time.

260. Charging Automotive Batteries from Farm-lighting Plant.—Owners of isolated farm-lighting plants may charge their automobile or radio batteries by connecting the battery either in series with the farm-plant battery or in parallel with it, using a suitable lamp bank for resistance. Since the farm-lighting battery is usually composed of sixteen cells giving 32 volts, and

since the voltage of the generator is approximately 40 volts, it is possible, with a majority of the plants, to charge one additional 6-volt battery at the same time the stationary cells are being charged by connecting it in series with them, as shown in Fig. 384. To secure the proper charging rate it may be necessary either to increase the engine speed slightly or to readjust the field rheostat, or both. If a 12-volt battery is to be charged, wire *C* should be connected to point *A* instead of to the end cell, thus cutting out three of the stationary cells.

In case the battery is to be charged off of the 16-cells through a lamp bank, 32-volt lamps should be used connected in parallel similar to the arrangement when charging off of 110 volts D.C. During the period of charge, the plant should be run at the charging rate so as to prevent excessive draining of the main batteries.

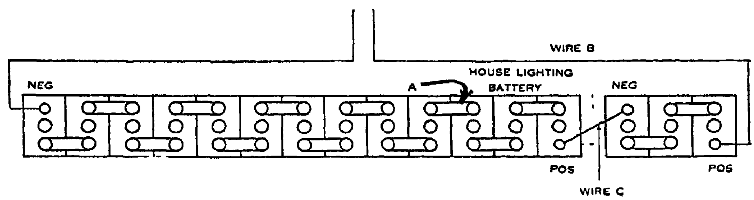


FIG. 384.—Method of connecting 6-volt battery in series with farm-lighting battery.

261. Rectifiers for Battery Charging.—When alternating current only is available for battery charging, some sort of rectifier must be provided for converting the alternating current into direct current suitable for charging. The various types of rectifiers used are as follows:

1. The chemical or electrolytic rectifier.
2. The electromagnetic or vibrating-type rectifier.
3. Mechanical rectifier.
4. The mercury arc rectifier.
5. The Tungar or bulb rectifier.
6. The motor generator.

In any type of rectifier, the main objective is to convert the alternating-current impulses into impulses of like polarity and continuous in direction in the battery circuit. This is the function of the commutator segments on the simple D.C. generator. One cycle of the alternating current is illustrated by Fig. 41, and the rectified current by Fig. 43. Some rectifiers operate on the

principle of utilizing every current impulse of the A.C. supply, while others use only every other impulse; that is, those of like polarity, as illustrated by Fig. 385.

As in charging from D.C lines, it is also necessary, when charging from an alternating current supply, to reduce the charging voltage to a value suitable for the batteries being charged. Alternating current provides a ready means of stepping the voltage either up or down by a transformer, the principles

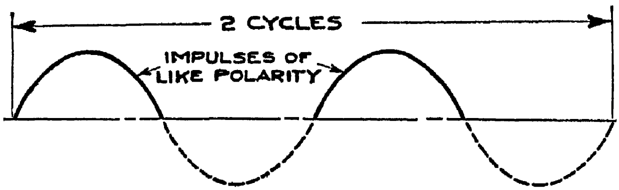


FIG 385 —Curve representing two alternating current cycles showing impulses of like polarity utilized by half-wave rectifiers.

of which were explained under Electromagnetic Induction in Sec. I Thus, most of the devices used for current rectification are equipped with transformers of the variable type, known as *auto-transformers*, in which the voltage may be increased or decreased by cutting in or out turns of the secondary winding.

262. The Electrolytic Rectifier.—The chemical or electrolytic rectifier is used mostly for "trickle" charging of batteries in storage and for radio "B" batteries where a low charging rate is required. It is based upon the principle of an electrical check valve in the form of an electrolytic cell which will allow current to pass through it in one direction only. The cell is usually composed of a plate of aluminum and a plate of lead or carbon submerged in a solution of ammonium phosphate. Let it be assumed that this cell is connected in circuit with a storage battery, as shown in Fig. 386. When the current flows from the aluminum to the lead, a thin coating of oxides and phosphates of aluminum is formed almost instantly on the aluminum plate. This coating is of such high resistance that the current is practically cut off until the direction is reversed. When the current reverses, this coating is instantly reduced and the current flows freely through the cell. Thus the current is free to pass through

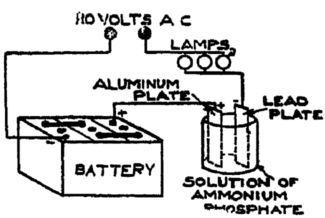


FIG. 386 —Single cell half-wave electrolytic rectifier.

the cell from lead to aluminum, but not from aluminum to lead. Consequently, if a battery is to be charged in circuit with the cell, it must be wired with the positive terminal connecting to the aluminum plate. As the internal resistance of this rectifier is fairly high, it makes it possible to control the charging rate within limits by varying the distance between the plates.

Using one electrolytic cell as shown, this type of rectifier is a half-wave device, but it is possible to use both waves by using four such cells connected as shown in Fig. 387. This type of rectifier is inefficient; consequently, it has given way to other methods for commercial charging.

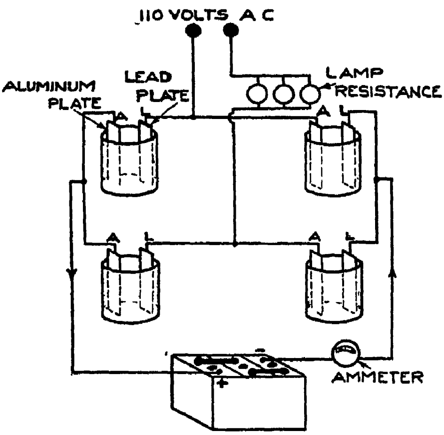


FIG. 387.—Four cell full-wave electrolytic rectifier.

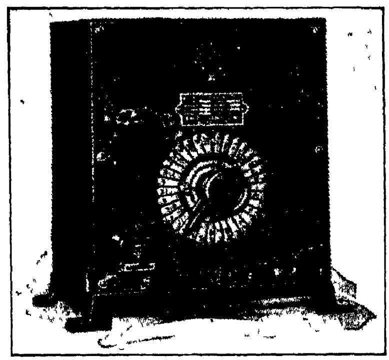


FIG 388 —King mechanical rectifier

263. Mechanical Rectifier.—A typical example of the mechanical rectifier is found in the King mechanical rectifier shown in Fig. 388. It consists principally of a small motor which drives a special commutator at such speed as to be in step with the alternating current. A special four-segment commutator is attached to one end of the armature shaft. On this commutator bear four brushes, two connecting with the alternating current and two with the battery-charging line. The connections made by the commutator during one revolution are shown in *A* of Fig. 389, while *B* of Fig. 389 shows the rectified current wave. By a study of the successive commutator positions it will be found that, if the motor drives it in step with the alternating current, the polarity of the two horizontal brushes which connect to the battery

circuit will be constant. Thus commutation and rectification take place in exactly the same way as in any direct-current generator. The battery-charging current is controlled by varying the charging voltage through an auto-transformer incorporated in the assembly.

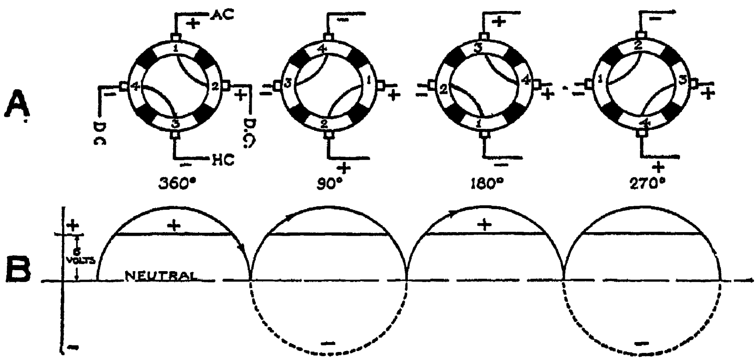


FIG. 389 —Principles of King mechanical rectifier. (*A*) Successive connections of commutator. (*B*) Current wave after rectification.

264. Electromagnetic or Vibrating-type Rectifiers.—Electromagnetic or vibrating-type rectifiers are used chiefly by car owners who are either unable or do not desire to take their

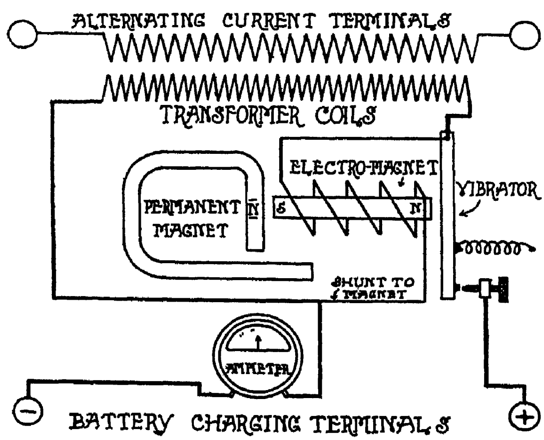


FIG. 390.—Circuit diagram of typical half-wave vibrating type rectifier.

battery to a battery station for recharging. With the advent of radio it has also been sold widely as a "home charger"; but, owing to its limitations, it is not suitable for commercial charging.

Vibrating-type rectifiers are divided into two types, the *half-wave* and the *full-wave* types.

The Half-wave Vibrating Rectifier.—In Fig. 390 the operating principle of the half-wave vibrating-type rectifier is illustrated. The alternating current is transformed in the usual manner. From the secondary winding of the transformer, the low-voltage charging current passes to a vibrating arm. This vibrating arm is controlled by a set of magnets on one side and a spring on the other, the circuit to the battery being completed when the contacts are closed.

A shunt winding, operated by current from the secondary coil of the transformer, is wound around a soft-iron core, one end of which comes fairly close to the vibrator arm. The other end of the core is separated by a minute air gap from the north pole of a strong permanent magnet.

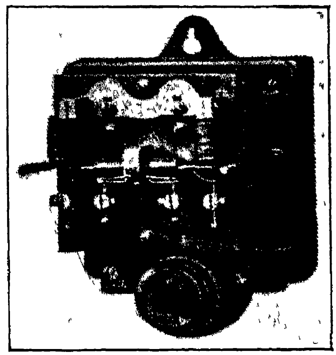


FIG 391 —Westinghouse vibrating rectifier.

When no current is flowing through the rectifier, the contact points are held open, due to the pull of the permanent magnet, acting through the soft-iron core on the contact vibrator arm. However, the vibrator spring is adjusted so that it will almost balance the pull of the core. Current passing in one direction through the core winding will add to the attraction of the magnet by magnetizing the soft-iron core in the same direction as it is magnetized by the permanent magnet, but current flowing through the winding in the opposite direction will neutralize the effect of the permanent magnet, and the vibrator points will be closed by the spring, thus allowing current to pass from the secondary of the transformer to the battery.

Practically this same type of rectifier is made in another style with the contact points on the opposite side of the vibrator arm. In this case the spring is used to break the circuit and is heavy enough to overcome the ordinary pull of the permanent magnet. With this construction the spring adjustment need not be so delicate; but, in any event, this type of rectifier requires very careful spring adjustment or the battery will be discharged instead of charged.

The Westinghouse Vibrating-type Rectifier.—The Westinghouse rectifier, Fig. 391, is a typical example of the full-wave-type vibrating rectifier. A circuit diagram of this device is shown in Fig. 392. In this rectifier two electromagnets are used in conjunction with a pivoted electromagnet, excited by current from the storage battery, and two sets of contact points. The usual step-down transformer is provided, the secondary or low-voltage winding being connected to the electromagnets and contact points as shown. The winding of these electromagnets is such that the upper and lower core ends of both electromagnets will always be of the same polarity, either

positive or negative, depending upon the direction of the current flowing. The pivoted bar is held normally in a horizontal position under the light spring tension of two flat springs, which are located one at each end of the bar. In this position, both sets of contacts should be open approximately the same distance and the same air gap should exist between the ends of the bar and the two electromagnet cores. When the battery, however, is connected for charging and the rectifier is turned on, the pivoted bar will be magnetized (with one end north and one end south) by current from the battery flowing through the coil of fine winding which it carries. Since the polarity of the two electromagnets will reverse with each reversal of

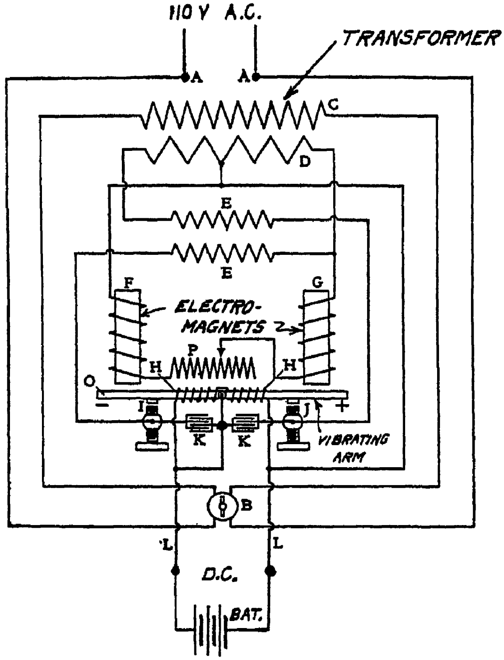


FIG. 392.—Circuit diagram of Westinghouse vibrating type rectifier.

the alternating current, the pivoted bar will be attracted and repelled by the alternating magnetism, with the result that it vibrates and alternately opens and closes the two sets of contact points in step with the alternating current. The result is that, during one-half cycle of the current, one set of points is closed, allowing induced current from the secondary winding to pass through them to the battery, while in the next half cycle the bar tilts in the other direction closing the other set of contacts, allowing the second half of the current wave to pass through the battery in the same direction as the first. To reduce sparking, a condenser is connected across each pair of contacts as shown.

With this type of rectifier, no attention need be paid to the polarity of the battery, as this is automatically taken care of by the reversal of the

magnetism in the vibrating bar. It is, however, very important to have the proper spring tension and freedom of the pivoted bar at all times, otherwise it may lag sufficiently behind the alternating current actually to cause discharging rather than charging of the battery. The Westinghouse rectifier is intended to operate on any 100- to 120-volt, 60-cycle A.C. circuit, charging one 6-volt battery at a time. The charging rate should be 8 to 8½ amp.

265. The Mercury Arc Rectifier.—The mercury arc rectifier may be considered as an electrical check valve, since it permits current to pass through it in one direction only. A circuit dia-

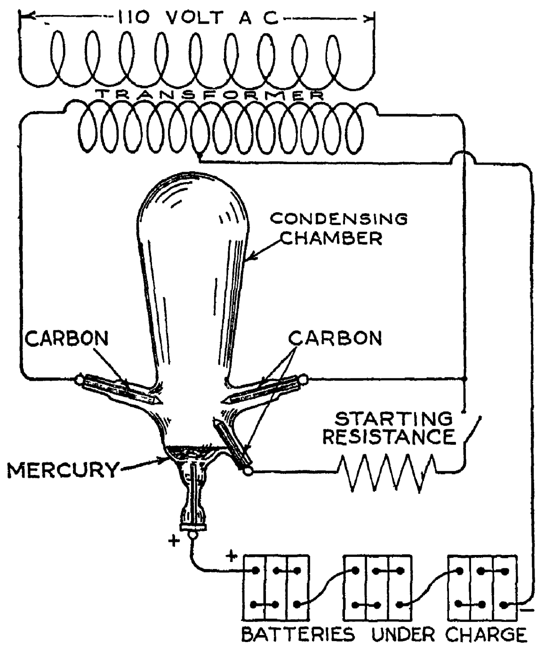


FIG. 393.—Circuits of typical mercury arc rectifier.

gram of a typical single-phase-type mercury arc rectifier is shown in Fig. 393.

The rectifier consists principally of a glass chamber or bulb from which the air has been exhausted and which has a pool of mercury in the bottom which makes electrical contact with a terminal extending through the bulb. There are also three other terminals of carbon extending through the bulb, one near the surface of the mercury (but not normally in contact with it) and used only in starting, the other two being located near the top

and on opposite sides of the bulb. In operation the terminal which is in contact with the mercury must be a cathode, or negative, while the other terminals must be anodes, or positive, in polarity with respect to the direction of current inside the bulb.

Operation.—The operation of the rectifier is based upon the principle that current will pass through a mercury vapor from a suitable terminal to a pool of mercury but will not pass in the reverse direction, namely, from the mercury, as positive, to the insulated electrode.

As will be noted, Fig. 393, the secondary winding of the transformer is divided into halves, the middle connection being connected to the battery, while the two outside ends terminate in the two upper bulb electrodes. One end of the secondary also connects through a starting resistance to the electrode located immediately above the mercury. The mercury electrode, which may be considered negative internally, but positive externally of the bulb, must connect to the positive terminal of the battery to be charged.

In order to start the rectifier, the alternating-current supply is turned on, then the bulb is tilted or rocked until the mercury bridges the two lower terminals, then recedes, causing an arc to form. The bulb will then fill with a mercury vapor, which acts as a conductor, establishing a circuit through the bulb, but only for that half of the secondary winding which makes the upper electrode positive and the mercury pool negative. Since the polarity of the secondary alternates with that of the primary, and since the bulb will permit current to pass through it in one direction only, namely, to the mercury, one-half of the secondary winding will deliver current to the batteries during one-half of the cycle and the other half of the winding will deliver current during the next half cycle. Thus, both current waves are utilized and the battery receives a pulsating direct current.

In most cases a reactance coil (a non-inductive winding) is connected in series with the battery to help maintain the arc in the bulb, while the alternating current is passing through the zero point of its cycle. This type of rectifier has been used extensively for charging vehicle batteries having 42 cells and for commercial charging, where a comparatively large number of cells are to be charged at one time. For volume charging, its efficiency is comparatively high, there being a voltage drop of approximately 14 volts through the bulb, thus making approximately 95 volts on a 110-volt outfit available for charging purposes. The efficiency will decrease as the number of batteries to be charged is reduced.

266. The Tungar Rectifier.—In principle, the Tungar Rectifier, Fig. 394, manufactured by the General Electric Company, is similar to the mercury-arc rectifier in that a glass bulb is used as an electrical check valve. The Tungar bulb, however, instead of containing mercury, is filled with a rare gas known as argon. The bulb also contains a tungsten filament (which is heated to incandescence by a portion of the transformer secondary winding)

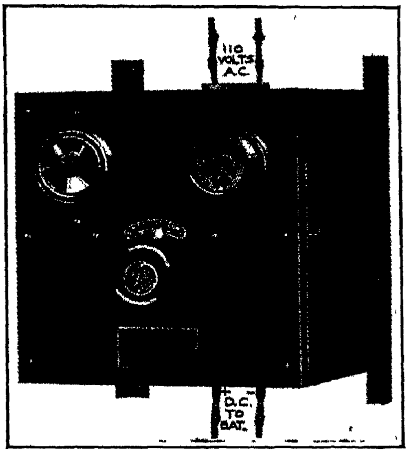


FIG. 394 —Tungar rectifier.

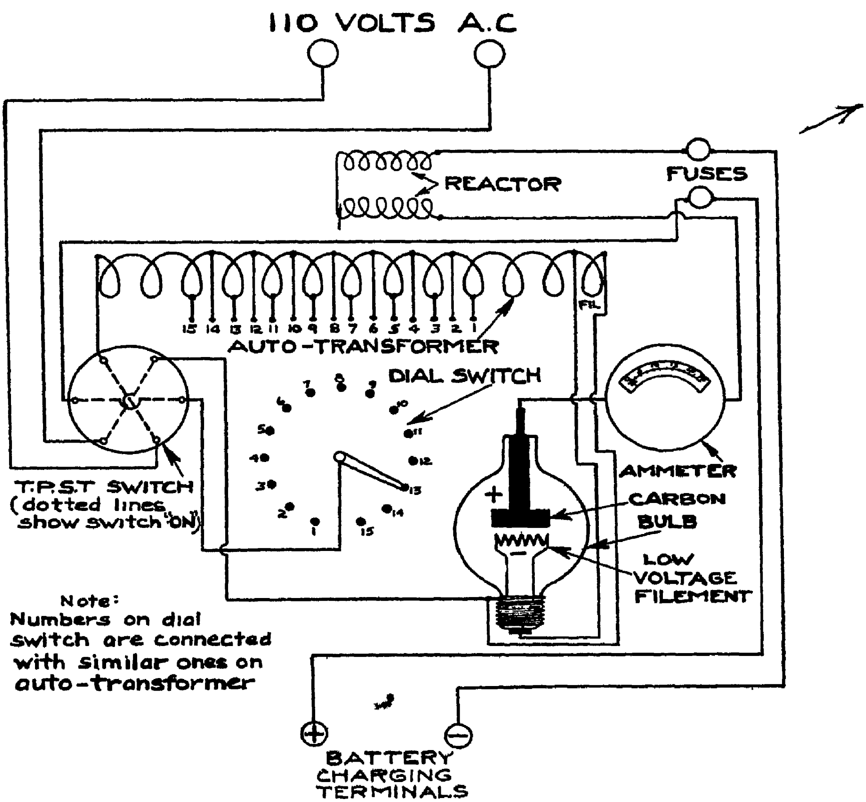


FIG. 395.—Circuit diagram of Tungar rectifier.

and a carbon block, which connects through the ammeter to the battery-charging circuit, as shown in the circuit diagram, Fig. 395. In operation the carbon block forms the positive or ~~cathode~~ terminal of the bulb, while the heated tungsten filament forms the negative or ~~anode~~ terminal. Such a bulb, having one cold and one hot electrode, acts as a rectifier, allowing current impulses to pass through the bulb from the carbon to the filament, but not from filament to carbon. The reason for this is explained as follows: During that part of the alternating current cycle in which the heated filament is of negative polarity, a stream of small particles of negative electricity, known as *electrons*, are projected from it. These bombard the cold positive carbon terminal, "ionizing" the argon gas, thus rendering it a conductor of electricity and allowing current to pass from the carbon to the filament. There is no corresponding action during the other half of the cycle when the heated filament is positive; consequently, no current will pass through the bulb during that half of the cycle.

It will thus be seen that such a rectifier—using one bulb as shown, is of the half-wave type, utilizing just half of the current wave. By the use of two bulbs properly connected, however, it will be possible to rectify both halves of the alternating-current wave, but this would be of no particular advantage, as the efficiency would not be increased. When two bulbs are used two separate charging lines are usually operated. In the 110-volt Tungar rectifier, a charging D.C. voltage of 75 volts is obtained, which is capable of charging ten three-cell batteries at one time at a charging rate of 1 to 6 amp. The charging rate should not be allowed to exceed 6 amp., as this would over-load and burn out the bulb. The efficiency of the rectifier on full load is approximately 75 per cent.

267. Motor Generator for Battery Charging.—As the name implies, motor generators used for battery charging consist usually of an alternating-current motor (operated from the source of current supply) driving a direct-current generator, which produces current of suitable voltage for battery charging. Usually the motor and the generator are two distinct machines mounted on a common base, the armature shafts being direct-connected by a suitable coupling; or the machine may be in the form of a single unit, known as a *rotary convertor*. In this event the armature is especially constructed to convert the alternating current, which is led in at one end of the machine, into direct

current, which is led out at the other. The motor generator may also be used to convert high-voltage direct current to low-voltage direct current where the conditions and the volume of business do not justify charging from high voltage.

Included with the motor-generator set there is usually a small control panel on which are mounted the necessary switches, ammeter, fuse block, automatic cutout relays, and the field rheostat for controlling the generator voltage, which, in turn, regulates the charging current. A typical motor-generator set of this type is shown in Fig. 396, which illustrates the Westinghouse set. This outfit is made in several sizes, ranging from 100 watts and

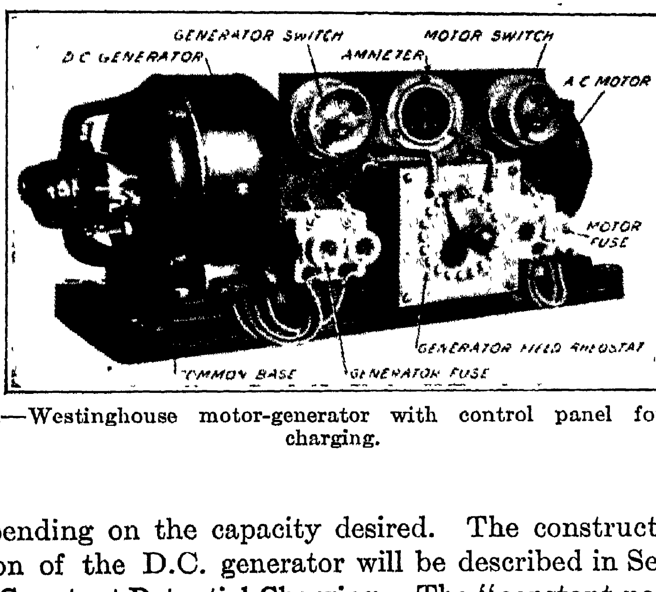


FIG. 396.—Westinghouse motor-generator with control panel for battery charging.

up, depending on the capacity desired. The construction and operation of the D.C. generator will be described in Sec. XXI.

268. Constant Potential Charging.—The "constant potential" system of battery charging is a recent development in battery-charging equipment and has a number of excellent features. The principle is not new, since it has been used in railway train lighting for many years, but only recently has it been widely adopted by automobile battery-charging stations. Although this system of charging in no way affects the method applied to the individual battery, the source of distribution to the battery is radically changed from the conventional high-voltage method of series charging.

The process consists essentially of connecting the battery to be charged directly across two charging mains or *bus bars* which are maintained at a constant voltage throughout the entire charging period of charge, the charging rate of the battery being controlled

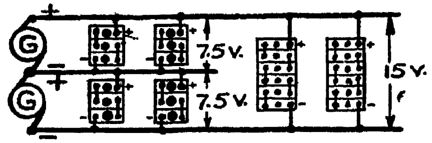
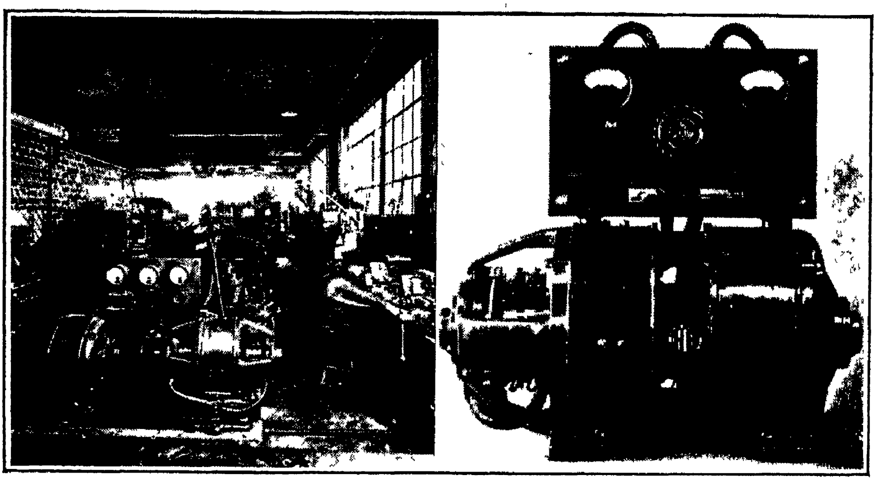


FIG. 397.—Polarity, voltages and method of connecting batteries in constant potential charging.

only by the internal resistance and countervoltage set up by the battery itself. In commercial charging, the voltage across the bus bars is maintained at 7.5 volts for 6-volt batteries and at 15.0 volts for 12-volt batteries. In order to charge both 6- and 12-volt batteries conveniently at the same time, three bus bars



(*A*) (*B*)

FIG. 398.—(*A*) Hobart Bros. constant potential charging unit, 400 ampere, 15-volt direct connected type. (*B*) Hobart Bros. single unit, 2-wire, 200 ampere constant potential charging set.

are used, having 15 volts across the two outside bars and 7½ volts across either the upper or lower pair of bars, the connections and polarities being as indicated in Fig. 397. With this arrangement the top bar is positive, the lower is negative, and the center

one either positive or negative, depending upon whether it operates with the upper or lower bus bar. Thus, when 12-volt batteries are to be charged they are connected across the two outside bars, while 6-volt batteries may be connected across either the upper or lower pair of bars as shown.

Since the batteries are charged in parallel, a generator capable of large current capacity at low voltage is essential. Furthermore, since its output is divided between two 6-volt charging lines,

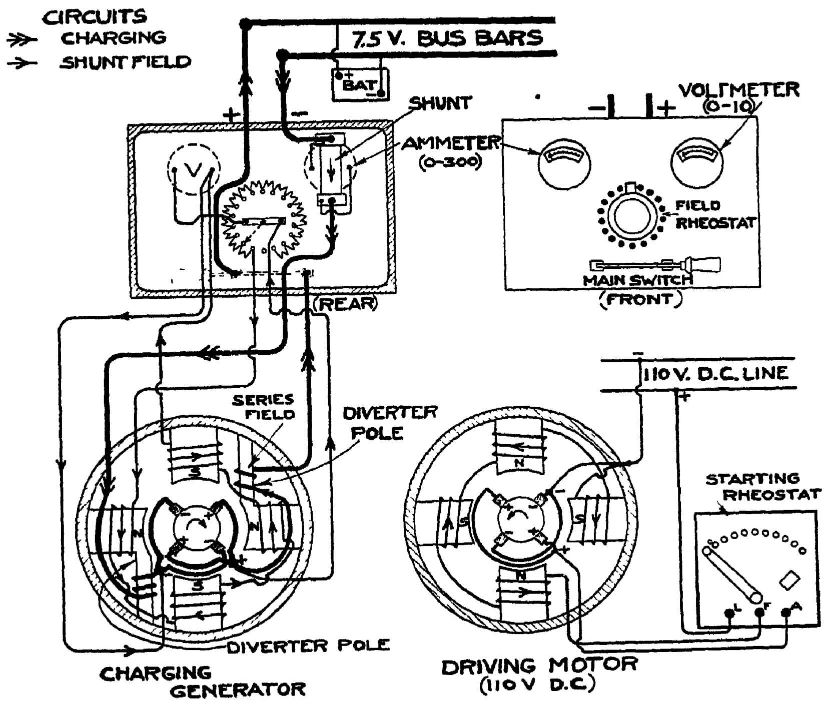


Fig. 399.—Circuit diagram of Hobart Bros. 200 ampere constant potential charging set, showing D C. motor

either the generator armature must be double-wound or two generators must be employed, each supplying half of the load. In Fig. 398*A* is shown a Hobart Brothers constant-potential charging set, 15-volt, 400-amp. size, which is typical of the double-wound armature type. The D.C. generator is shown at the right and the 5-hp. A.C. motor which drives it is at the left. It also shows the instrument panel on which are mounted two ammeters, one in each charging line, a low-reading voltmeter to indicate the

voltage of the bus bars, and a rheostat to regulate the shunt field current and, consequently, the generator voltage. In Fig. 398*B* is shown the HB single-unit 200-amp. outfit, while a circuit diagram of the same unit is shown in Fig. 399. At the left is given the wiring for the generator and at the right the wiring for the driving motor, the one shown being a 110-volt D.C. motor. The usual driving motor, however, is of the A.C. induction type.

In the double-wound armature or three-bus bar type, the generator armature has two separate windings and commutators, each delivering 7.5 volts. Thus, in order to obtain both 7.5 volts and 15.0 volts for charging, they are connected in series with a connection tapped between the commutators leading to the center or neutral bus bar, as shown in Fig. 397. Thus, one armature winding and commutator feeds current to the batteries connected to the upper two bus bars and the other commutator to the lower two bus bars. It will, therefore, be advisable to have approximately the same number of batteries connected on each side of the line, in order to balance the load as much as possible on the two windings—at least within 25 per cent—to insure proper voltage regulation.

It is obvious that regulation of the constant-potential generator is important, since a slight change in voltage will make a great difference in the battery-charging rate. Furthermore, the voltage tends to vary with a change in the charging load and temperature, so that an attendant should be on hand to observe the voltage from time to time and adjust it if necessary. The generators are usually shunt-wound—either self- or separately-excited—and slightly compounded, that is, the fields have some series winding working accumulative with the shunt winding, to give the generator better voltage characteristics. Methods of generator regulation will be described in detail in Sec. XXIII.

269. Characteristics of Constant-potential Charging.—Since the applied charging voltage is maintained constant at about 2.5 volts per cell throughout the entire charging period, and since the internal resistance and counter voltage of the battery vary with the condition of the battery, a battery which is discharged, yet in a healthy condition, will draw a high-charging rate at the beginning of charge but will draw less and less as the counter-voltage rises. It is thus said to receive a tapering charge. The charging rate at the start may be as high as 30 to 60 amp., but

as a rule it does not become injurious, since the battery does not gas materially when in a discharged state. Furthermore, the charging rate is only limited by excessive heating, which will not occur unless the battery is in a badly sulphated condition. In case the battery should be badly sulphated, the charging rate should be reduced by connecting a suitable resistance—usually a coil of ordinary bailing wire is sufficient—in series with it.

The variation in charging rate, specific gravity, voltage, and temperature during charge is clearly illustrated by the curves

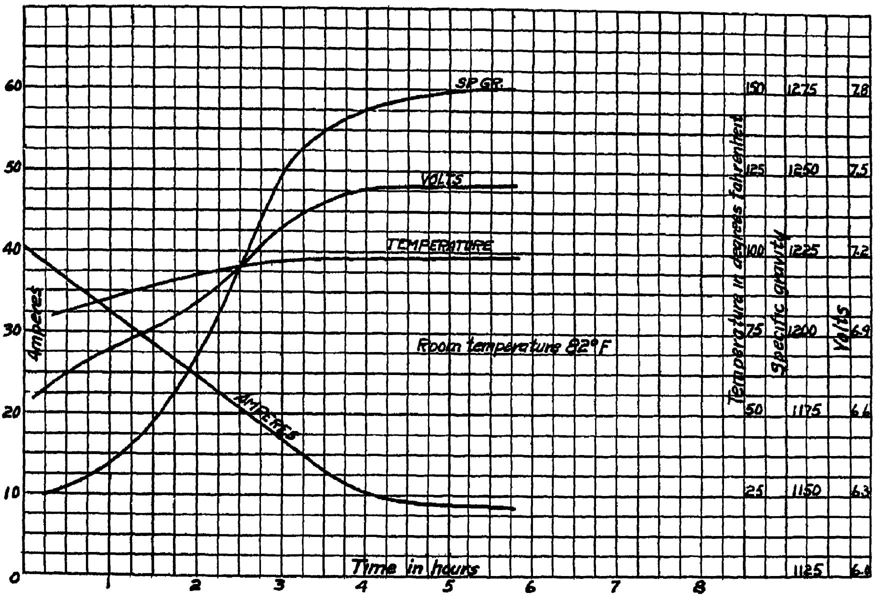


FIG. 400.—Curves showing characteristics of constant potential charging

in Fig. 400, which show the characteristics of a 100-amp.-hr. starting and lighting battery being charged by a HB (Hobart Brothers) constant-potential system. From a study of these curves it will be noted that by the end of the first 3 hr. of charging, the specific gravity has risen from 1.150 to 1.250, indicating that three-fourths of the charge has gone into the battery. Also, that even at the high charging rate—starting at 40 amp. and dropping gradually to 17 amp.—the temperature is only 98 deg. F. with the room temperature at 82 deg. F. It will also be noted that the charging current drops gradually to the

finish rate and that the battery becomes fully charged in approximately 6-hr. time. This period is approximately one-half to one-third the time required in series charging at the normal start and finish rates.

270. Advantages and Disadvantages of Constant-potential Charging.—The advantages claimed for constant-potential charging over the high-voltage series method of charging may be listed as follows:

1. It enables the service station to guarantee 8- to 10-hr. charging service.
2. It reduces the required number of rental batteries.
3. It reduces the power consumption 30 to 35 per cent.
4. It reduces labor expense in handling batteries.
5. It permits all sizes of batteries to be charged at the same time regardless of ampere-hour capacity, each receiving the proper rate, for example, motor-cycle batteries may be charged along with starting batteries.
6. It affords a ready means of determining battery condition, so that a report can be made immediately to the owner as soon as the battery is put on charge. If the battery is defective and must be torn down for rebuilding, it will be indicated by sudden overloading and choking down of the generator accompanied by a groaning sound; also, by over-heating of the defective cells.
7. The batteries can be put on charge or taken off at will without disturbing the other batteries on the line.
8. Gassing is reduced, due to the tapering charge.

The principal disadvantages of constant-potential charging may be summed up as follows:

1. The high initial cost of charging equipment
2. More storage space for cars required when 8- to 10-hr charging service is given. This applies particularly to stations handling a large volume of business daily.
3. It is not particularly adapted to the forming or initial charging of new batteries where low charging rates are required.
4. Possible injury to the battery in case an inexperienced service man should connect the battery on charge with reverse polarity.
5. Possible reversal of the polarity of the generator, if it is of the compounded type, in case the power should go off with a large number of batteries charging. This should cause no trouble, however, if the system is operated by a competent attendant.

SECTION XVI

BATTERY TROUBLES AND REMEDIES

271. Normal Wear and Service of Automobile Batteries.—Owing to the varied conditions under which the automobile battery must operate, such as changes in temperature, vibration, excessive charging and discharging rates, as well as neglect on the part of the user, there are many things which will cause a battery to become inoperative and to need special attention and repairs. If given the proper care as to charging, filling, etc., a battery should be normally good for three to four years' active service and in many instances batteries have been known to have lives of five—and even nine years—with only such repairs as new separators and an occasional recharge with the battery removed from the car.

An important factor controlling the life of the battery is the characteristics of the charging generator and the normal rates at which the battery is charged. In some cases the battery will receive practically the same charging rate at all speeds regardless of the battery condition, while in other instances the generator is regulated so as to give the battery a tapering charge. Furthermore, at the normal speeds at which the car is driven, some generators will not charge the battery sufficiently to keep it charged, especially if the car is driven on short runs and with considerable night driving; while other generators will tend to over-charge the battery, causing it to heat and gas excessively with a deteriorating effect. Thus, the life of the battery will depend upon many factors. The following pages will cover the most common battery troubles, outlining their causes and the methods of remedy.

272. Battery Discharged or Weak.—If the storage battery that is used in automobile service appears dead or shows lack of power, as indicated by poor operation of the starting motor, dim lights, and feeble ignition, it is evident that the fault lies either in the

battery itself or in its connections. The trouble may be due directly or indirectly to one or more of the following causes: (1) battery discharged, (2) low electrolyte, (3) defective insulation, (4) plates abnormally sulphated, (5) corroded terminals, (6) broken or loose terminal or plate connections, (7) worn-out or defective plates, and (8) battery of too small capacity.

Usually the hydrometer test can be used to determine the condition of charge. However, should the electrolyte be at too low a level to test, the voltage of each cell should be taken, and, if any cell drops below 1.7 volts during cranking with the starter, the battery should be removed, given a thorough charging, and checked for all other troubles. This same procedure should also be followed if the specific gravity shows much less than a half charge, as it will be difficult for the generator on the car to bring the battery up to a full state of charge.

If the battery proves to have little charge, and it is a problem of getting the engine started with the battery in this condition, and if ignition is supplied by the battery, the engine will usually receive better ignition and start more readily if cranked by hand, because, without the starter in operation, requiring a high discharge rate, the battery terminal voltage will be considerably higher, enabling a better ignition spark to be produced.

273. If Battery Will Not Stay Charged.—If, after a battery is fully recharged, it will not stay charged by the normal running of the car, the trouble may be due to one or more of the following causes:

1. *Generator Not Charging.*—(See Art. 342.)

2. *Charging Rate of Battery Too Low.*—This may be due either to the car being run too little with lights off or at insufficient speed for the generator to replace the current that is taken from the battery when the lamps are burning with the engine idle, or to running at very low speed. Insufficient charging may also be due to improper adjustment of the generator regulation, to defects in generator windings, or slipping of the generator driving belt or clutch. The proper method of adjusting the generator charging rate is explained in Art. 443.

3. *A "Ground" or "Short Circuit" in the Wiring.*—With the engine idle and all switches "off," this trouble may be detected by disconnecting the battery wire and touching it lightly a few times on the battery terminal from which it was disconnected. If a spark is produced, a ground should be looked for in the wiring between the battery and the generator cutout and between the battery and the lighting switch. Another possibility is that the contact points of the cutout are not properly opened. Electrical

leakage may also result, due to spilled electrolyte remaining on top of the battery or through an acid soaked battery box.

4. *The Cutout Relay Not Operating Properly.*—The cutout should be tested to see that it is closing and opening the battery-charging circuit properly. The cutout contacts should remain in the open position when the engine and generator are not running and should stay in the closed position when the engine is running above the "cut-in" speed, which is usually from 7 to 10 m p.h. If the cutout does not close properly, the trouble may be due to an open in the voltage-coil circuit (the fine winding of the cutout), oil on the generator brushes or commutator, worn brushes, high mica, improper brush tension, loose or dirty terminal connections on either the generator or the cutout, blown fuse, or a heavy "short" across the main brushes. For operation and adjustment of the cutout, see Arts. 344 and 345.

5. *Excessive Use of Starting Motor.*—The starting motor draws a heavy current while cranking the engine, thus discharging the storage battery rapidly. The car should not be propelled with the starting motor. If this becomes necessary, in an emergency, the driver should shift gears into *intermediate* or *low*, so as to reduce the current consumption of the starting motor. In case the battery has been discharged through excessive use of the starting motor, it is usually advisable to remove the battery and charge from another source of current until fully charged. If this is impossible, it may be brought up to fully charged condition through continuous use of the car, or running of the engine, by using the lights and the starter sparingly, and preferably, cranking by hand.

6. *Excessive Load on Battery.*—Many battery troubles are caused by adding extra electrical accessories or increasing the size of lamp bulbs, thereby increasing the current load above that intended for the system. With such an increased load a battery of larger capacity should be used and the generator-charging rate increased in proportion, provided it does not overload the generator.

7. *Battery Too Small.*—The battery in the system may be too small for the capacity required, that is, it may have insufficient plate area. The effect will be similar if the plates are partly sulphated. The remedy is, naturally, the installation of a battery having a larger capacity, or the removal of sulphation through charging.

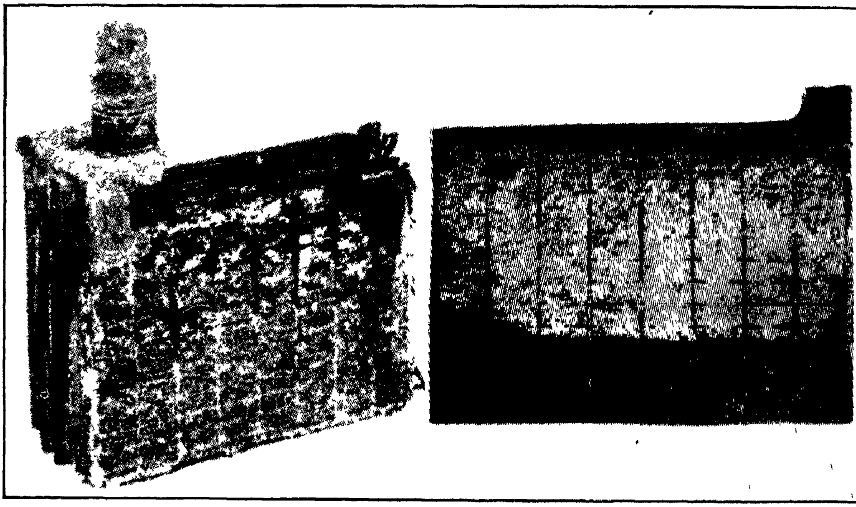
8. *Broken-down Insulation.*—When particular cells will not hold a charge, the trouble is usually due to broken-down insulation caused by the separators not insulating the plates properly, or to high sediment in the bottom of the jar bridging the lower portion of the plates. In either case the cells so affected must be taken apart either to install new separators or to clean out the sediment, or both, as the case may require.

9. *Cracked Jar.*—A jar may become cracked by rough handling of the battery, freezing, or buckling of the plates, causing the loss of electrolyte. A cracked jar is indicated by the battery becoming wet on the bottom and the necessity of more frequent filling of the affected cell. Frequent filling, in turn, causes weakening of the electrolyte, thus lowering the cell specific gravity and capacity. The remedy is to replace the jar and electrolyte, and

charge the cells to the same capacity. A test for cracked jars is given in Art. 292.

10. *Defective Plates.*—The plates may become defective so as to effect their capacity due to (*a*) abnormal sulphation, (*b*) over-heating, (*c*) buckling, (*d*) freezing, and (*e*) shedding of the active material from the grid through wear. *Over-sulphated* plates may usually be revived by long charging at a low rate, but the other troubles are more or less destructive to the plates with no remedy other than to replace them. Each of the above troubles can largely be avoided by keeping the battery in a fully charged condition.

11. *Corroded or Loose Terminals.*—The battery may also show loss of capacity because of corroded or loose terminals, which prevent it from being charged properly, due to the high resistance offered to the flow of current by either corrosion or the loose connection. The remedy is to clean and retighten the terminals and make sure that the generator is charging properly.



(*A*) (*B*)

FIG. 401.—(*A*) Sample of sulphated positive battery plates due to under charging. (*B*) Sample of sulphated negative plate due to low electrolyte.

274. Abnormal or Over-sulphation.—The direct result of undercharging or "starvation" of the battery is over-sulphation of the plates, which, in turn, reduces the effective plate area and consequently the battery capacity. As outlined in Art. 228, if a battery is allowed to remain in a sulphated condition for any length of time, the sulphate will gradually harden into a white crystalline formation, which is a poor conductor of electricity, thereby tending to seal up a good portion of the pores of the

plates. A good example of this is shown in Fig. 401*A*, which shows a positive group with separators that have been operated in a partially discharged condition for some length of time. The white area of the plate indicates the sulphation.

Over-sulphation may also result from neglect in filling or allowing the electrolyte to get below the tops of the plates. Such a condition is illustrated by Fig. 401*B*. This clearly shows that the plate was only about one-third covered with the electrolyte, the upper portion being allowed to dry out and to sulphate as indicated by the white area. With a portion of the plate becoming inoperative on account of the sulphation, the unaffected portions will then be over-worked on discharge, especially during cranking, and over-charged during the charging period. This, in turn, causes over-heating of the effective plate area, distorting or *buckling* of the plate, and finally a rapid shedding of the active material.

From the above it is evident that the ampere-hour capacity will be materially reduced by over-sulphation. For example, the capacity of a 100-amp.-hr. battery in which the plate area is one-half sealed up by sulphation will be reduced approximately 50 per cent and will be capable of no more work than a battery of 50-amp.-hr. capacity. Furthermore, if its charge and discharge rates are such as are intended for a healthy 100-amp.-hr. battery, the active plate surfaces will naturally be over-worked.

275. Effect of Underfilling or Low Electrolyte.—Lack of proper filling or a cracked jar naturally causes the level of the electrolyte to fall below the tops of the plates, exposing not only the plates but the separators to the action of the air. If the plates should be uncovered and allowed to dry out while in a discharged condition, over-sulphation soon sets in, the exposed portion of the plates turning to a white crystalline formation, as shown in Fig. 402. The separators, Fig. 403, will also dry out, crack, and carbonize, due to the action of the acid. The lower or submerged portion of the plates and separators will remain fairly active, as indicated by the normal color they retain, but will be over-worked due to the reduced active plate area, causing over-heating and rapid deterioration of both the plates and the separators. This trouble is aggravated still more by the greater concentration of the acid, due to the lack of water, which, coupled with the

higher operating temperatures, attacks the grids and separators causing the grids to corrode and the separators to carbonize.

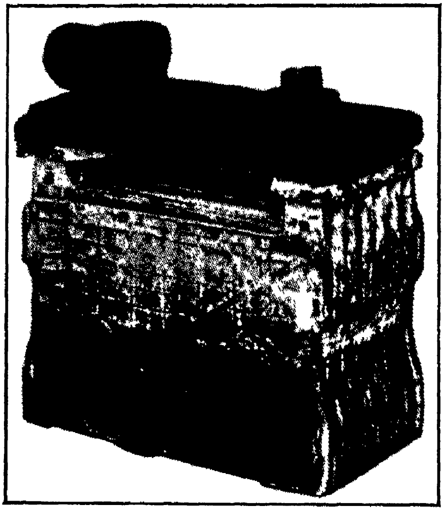


FIG. 402.—Effect of low electrolyte.

Sometimes it will be found that the upper portion of the plates and separators will be covered with a white flaky formation as in Fig. 404, while the lower portion retains its normal color. This

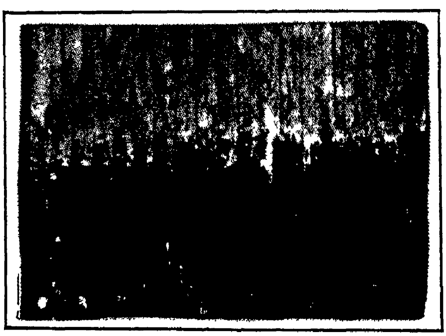


FIG. 403.—Effect of under-filling or leaky jar on wood separator.

white substance is usually termed "sulphate," but it is doubtful whether it is, for in order to produce such a quantity of sulphate a large amount of sulphuric acid must be present, which is not always the case. As a matter of fact, this white flaky material

forms when there is little acid in the plates, even when they are covered with water.

The probable explanation of this is as follows:

The battery has probably been operated for some time with low electrolyte, as indicated by the lower edge of the white band. It was then discovered that too little electrolyte was present and pure water was added to fill the cells, but the battery was allowed to stand in this condition without charging. The result was that the acid, being heavier than water, remained at the bottom of the cell at its former level, while the pure water in contact with the upper half of the plates, which were previously partially or entirely in a discharged state, produced a chemical action, the formation (H_2PbO_3), white in color, accumulating on the upper half of the plates and separators. Since lead hydrate is much harder to remove than lead sulphate, an element thus coated is practically useless.

276. Treatment for Abnormal Sulphation.—The only remedy for an over-sulphated battery is prolonged charging at a low rate. The exact rate at which to charge it will be determined by the size of the battery and the extent of sulphation, but usually it will require the finish or 24-hr. charge rate, or less—say, 2 to 6 amp. The charge can be carried on at such a rate that the temperature of the battery at no time rises above 110 deg. F. as measured by a thermometer inserted through the vent-plug opening. The charging current should be as high as possible without causing excessive heating, and should be increased slightly as the charge progresses. Gassing will finally take place, just as it does in a normal battery that has reached a fully charged condition, at which time the charging rate should be lowered.

When the battery has reached a fully charged condition, as indicated by vigorous gassing at the low charging rate, and shows no rise in specific gravity over a period of several hours, it should be removed from the charging line and discharged at a rate of 8 to 10 amp. until the specific gravity falls to the normal discharge point of 1.150. It should then be recharged at a low rate as before, increasing the charging rate as much as possible without causing excessive heating. The battery should be put through several cycles of charge and discharge until the plates regain their normal healthy condition. This may be checked by putting the battery on high discharge test and by the cadmium test. From one to two weeks' time may be required for this treatment.

277. Reversed Cell Polarity.—In testing the voltage of a battery it may be found that one or more cells have a reversed polarity. At first, this would seem to indicate that the battery had been improperly assembled. This may be the case, but more often it is because the cell in question has for some reason become discharged more than the others and the charging received by the battery was not sufficient to bring it up. In fact, the cell became discharged to such a low point that the discharge current from the other good cells through it was sufficient to actually reverse the polarity of the plates, converting the positive plates into negatives and the negatives into positives. The same effect would be produced in all the cells if the entire battery were charged in the wrong direction.

The usual remedy, if the cell is not too badly injured, is to charge the affected cell in the proper direction until it shows the same state of charge and capacity as the other cells. Reversing of the cell polarity is usually more or less injurious to the life of the plates and should be avoided if possible.

FIG. 404.—Lead hydrate formation on plates due to under-filling and under-charging.

FIG. 405.—Example of buckled positive plates.

278. Over-charging.—Over-charging means *excessive gassing* and, usually, *over-heating*, both of which produce harmful effects. Gassing tends to cause shedding of the active material from the plates and rapid evaporation of the electrolyte, necessitating frequent filling, while over-heating causes buckling of the plates, FIG. 405 (particularly if the plates are badly sulphated), and

disintegration of the active material. A good example of this is shown in Fig. 406.

Over-charging on the car is usually due to improper regulation of the generator, or continuous charging at high rates on long drives with the battery fully charged. In case long day drives are to be made with practically no current being used other than for ignition, the battery cells should be properly filled with water—usually added each day—and the temperature of the battery watched. If the battery connections feel warm to the hand, it indicates the cell is over blood temperature, 98 deg. F., and that the charging rate should be either reduced or stopped. The charging rate can readily be reduced by burning the headlights, or it may be stopped

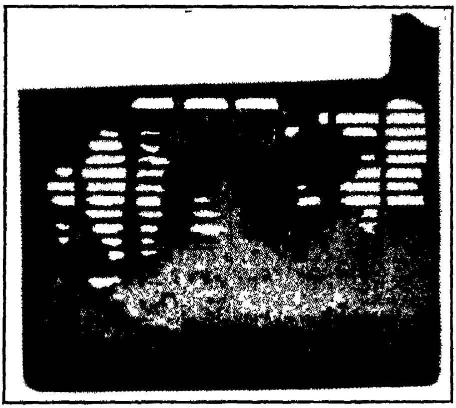


FIG. 406.—Result to negative plate from over-heating due to charging at too high a rate. The acid line is also shown.

entirely by either removing the shunt field fuse on the generator, or short-circuiting the main generator brushes.

279. Treatment of Buckled Plates.—If the plates are badly buckled, yet the positive plates (usually the first to wear out) are in fair physical condition, they may be straightened and put back into service with fair results. Before any attempt is made to straighten the plates, however, they should be fully charged, if possible, to render them more pliable. To straighten the plates, remove the separators one at a time, then place boards of suitable thickness between the plates of the group to be straightened, using fairly heavy boards for the two outside ones. The assembly should then be pressed in a vise, as shown in Fig. 407, the pressure being applied gradually. The group should be left in the vise several minutes to give the plates a chance to straighten without

undue strain. In assembling the groups, new separators should be used.

FIG. 407.—Method of straightening buckled plates.

280. Granular or Disintegrated Plates.—If a cell becomes over-heated, that is, over 110 deg. F., the active material of the plates gradually becomes soft and in the case of positive plates

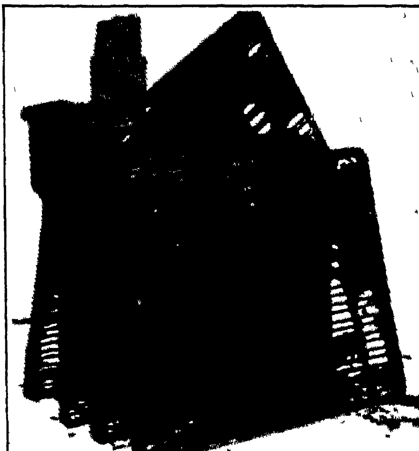


FIG. 408—Effect of continuous over-heating on positive plates.

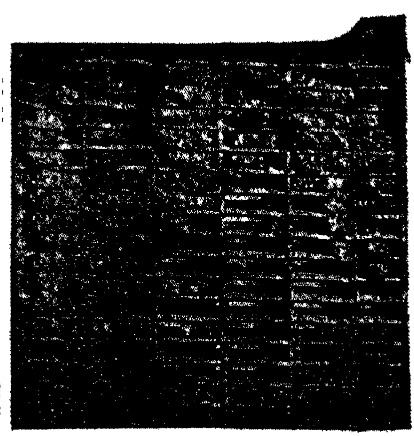


FIG. 409.—A worn out battery plate from which considerable active material has fallen, exposing the grid.

it has a tendency to free itself from the grid and wash down as sediment in the mud spaces below the plates. Over-heating also causes the acid to attack the plate grids, causing them to become

weak and to crack readily. In the negative plates the active material does not drop out so readily, but it softens and swells and becomes granular or sandy instead of maintaining a rubber-like texture as when in a healthy spongy condition.

After over-heating has occurred, the battery capacity may be somewhat higher for a time, due to the greater porosity of the active material, but the material rapidly disintegrates and falls out. Figure 408 shows what continuous over-heating does to the positive plates. The only remedy is new plates.

281. Sediment.—Sediment may not be classed as a battery disease, but merely as the natural consequence of the plates shedding their active material. This will take place through normal wear of the plates due to charging and discharging and through vibration of the plates due to jolting of the battery in service. Excessive gassing of the cell during charge stimulates shedding, as the gas bubbles that form in the outer pores of the active material tend to pick particles of it loose from the plates which fall to the sediment space below. Excessive gassing is usually accompanied by over-heating which softens and disintegrates the active material, making "shedding" still more rapid. Figure 409 shows a worn-out battery plate from which a large portion of active material has fallen out, forming sediment in the bottom of the cell. In time, this sediment may fill the *mud* space below the plates, causing a short circuit between the plates at their lower edges. This, in turn, causes local action and internal discharging of the plates, as a punctured separator would, thus preventing the cell from holding a charge. In this event the element must be removed and the sediment cleaned out.

282. Separator Troubles.—The purpose of the separator is to insulate the plates it separates. If it does not, the internal short circuit which forms, either by direct metallic contact or by active material bridging or treeing between the plates, sets up a local action, causing the cell to discharge itself internally. The failure of the separator may be due to: (1) The kind and quality of the wood used, (2) charring or carbonizing of the wood by excessive heat and strong electrolyte, (3) pinching of the wood fibers at the edges by buckling of the plates, (4) wearing too thin from normal wear, and (5) cracks, due to allowing the separator to dry by exposure to the air.

The ability of the separator to withstand wear and cracking depends upon the crushing and shearing strength of the wood, while its porosity is governed by the kind of wood used, the way it is cut as to direction of grain, and the thoroughness with which it has been treated to remove the acetic acid and other harmful juices.

Various woods are used for separators, but they differ considerably in their characteristics. Basswood has great porosity, but lacks strength and disintegrates rapidly in sulphuric acid. Redwood, cypress, and fir are also used to some extent, but Port Orford cedar is usually considered the best wood for this purpose. It has great porosity, firm fiber, great crushing and shearing strength, and resists disintegration in acid better than the other woods.

The relative strength of the various woods, when dry, is given in the following table:

Kind of wood	Strength in pounds per square inch	
	Crushing	Shearing
Port Orford cedar	1,020	1,500
Douglas fir...	950	1,080
Redwood...	840	900
Poplar.. . .	740	1,170
Cypress . . .	960	1,120
Basswood	580	1,240

In choosing separators, it is a good plan to examine them carefully for sawtooth marks on the back, as these indicate that they were sawed from the log instead of shaved with a knife, as is thin wood to be used as veneer. The circular-sawed-type separator is to be preferred, as it will not crack so readily as the other types.

283. Installing New Separators.—In reinsulating the plates, new separators should be cut large enough so that they extend approximately $\frac{1}{8}$ in. beyond the edges of the plates on all sides except the bottom, where they should be flush with the bottom of the plates. They should be placed between the plates so that

the ribbed or corrugated sides are next to the positive plates and run vertical when the elements are in their natural positions. With wood separators, care should be taken not to use the old separators again, or to use separators that have not been properly treated. Any separators which are cracked, worn thin, carbonized, or have been allowed to dry out since treatment should be discarded, as cracks will form with the battery in service, causing treeing of the active material. In the threaded-rubber separators, sometimes the old ones may be used again if they have not become worn too thin or cracked.

284. Indications of Broken-down Insulation.—Broken-down insulation, due to either high sediment or defective separators, is indicated when a cell will not hold a charge on open circuit. Other indications of broken-down insulation are (1) undue heating of the cells upon charging, (2) little or no voltage or gravity rise after a prolonged charge, and (3) the fact that the cells cannot be made to gas properly. Such a cell is considered *dead* and can be remedied only by dismantling and either removing the sediment or renewing the separators, or both.

285. Effect of Impurities in Electrolyte.—Impurities may be introduced in the electrolyte by the use of impure water in filling, or by using separators that have not been properly treated. Water drawn from a well, spring, or iron pipe usually contains metals and salts of various kinds which will be deposited in the pores of the plates and separators, greatly decreasing the life and activity of the battery. Iron is especially hard to get rid of, once it enters the cell, because it will pass back and forth between the positive and negative plates during charge and discharge. Should separators be used which have not been treated to remove the acetic acid, this acid will prove very troublesome, especially when the cell becomes over-heated as this drives it out of the wood into the electrolyte. Acetic acid damages the grids principally, sulphating and corroding them until they become weak and broken. The presence of acetic acid is indicated by its vinegar smell when heated, and foaming when the battery is charging.

Dope Solutions—Sometimes impurities or foreign liquids are introduced into the battery by misinformed owners in an attempt to charge it, to obtain greater capacity, or prevent it from freezing. Such procedure will usually only bring disastrous results

by injuring the plates and separators and by decreasing the life of the battery. So-called "patented" electrolytes should be strictly avoided, as they are usually injurious to the battery life and so far have generally not been found to have special merit. *Only chemically pure sulphuric acid and distilled water of proper specific gravity should be used in the battery to give the best results.*

286. Procedure if Impure Electrolyte Is Found in the Battery.—If it seems probable that impurities have entered the cells, the remedy is to give the battery a complete charge, then empty the old electrolyte and replace it with new of 1.280 specific gravity. By fully charging the cells, most of the impurities will be driven into the electrolyte and they will be gotten rid of when the solution is emptied out.

FIG. 410.—Effect of strong electrolyte on wood separator.

287. Effect of Strong Electrolyte.—Acid stronger than 1.350 to 1.400 specific gravity should not be poured into a cell in adjusting the gravity of the solution. Furthermore, the maximum strength of the electrolyte should not exceed 1.300 when the plates are fully charged, because acid stronger than 1.300 specific gravity will attack the grids of the plates, causing them to sulphate and crack, and the separators to carbonize and crumble. The effect of strong acid on wood separators is clearly shown in Fig. 410.

288. Effect of Over-filling.—The battery should be filled with pure distilled water to a level approximately 3/8 to 1/2 in. above the tops of the plates. If the battery is filled above this level, the

electrolyte will run over during charging, because it expands considerably on account of the gas bubbles in it and because of the rise in temperature. This will result in a loss of the electrolyte and in an eating away of the battery box, as indicated in Fig. 411. The box becoming acid-soaked may also result in leakage of current from the battery terminals to the metal work on the car, thus causing the battery to discharge. Such a condition may also result from the vent plugs not being screwed in place or from a crack in the sealing of the tops of the cells. As shown in Fig. 411, the acid solution attacks the wood and in a short time the case may become so soft that the handles break or pull off and the battery becomes loose in its compartment. To make sure that

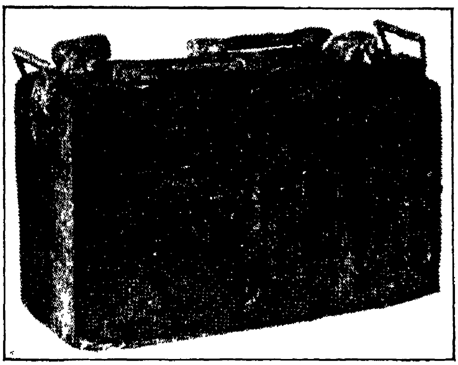


FIG. 411.—Result of over-filling.

the cells will not be damaged through vibration, the case should be thoroughly dried out, then repainted with an acid-proof paint, and new hold-downs provided. If deterioration, however, has gone as far as that shown in Fig. 411, the case must be renewed.

289. Corroded Terminals and Hold-down Clamps.—The terminals and connectors frequently become covered with a greenish deposit known as copper sulphate. This is a corrosion due to the acid fumes which are constantly passing off from the cells and attacking the copper surfaces of the connectors. Figure 412 shows a cable terminal badly corroded by the splashing or spraying of electrolyte on the bare cable wires where the insulation has been stripped off.

The action of the acid on the hold-down rods or clamps is similar. These are usually made of iron, and electrolyte quickly attacks them, causing a yellowish-white corrosion, or iron sulphate. If not taken care of, the hold-down will become entirely eaten through and no longer able to hold the battery in position.

The eating action of the acid may be stopped and all corrosion removed by washing the parts either in a solution of bicarbonate of soda (common baking soda) or in dilute ammonia, and brushing them with a stiff brush. They should then be washed with water and wiped dry. Further corrosion will be prevented by covering the parts with a light coat of vaseline or soft grease.

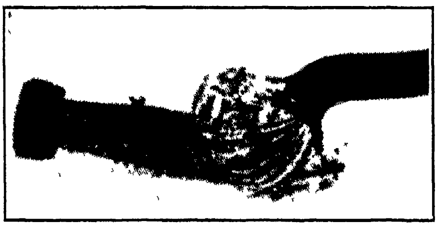


Fig. 412.—Effect of corrosion on battery cable connection.

290. Effects of Freezing.—The freezing point of electrolyte depends upon its specific gravity as given in the following table:

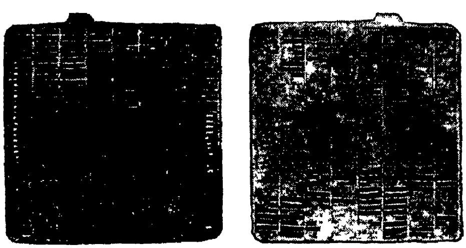
Specific Gravity (Hydrometer Reading)	Freezing Temperature (Degrees Fahrenheit)
1 050	+27
1.100	+18
1.150	+ 5
1.164	0
1.200	−17
1.250	−61
1.275 to 1.300	−90

Thus, to prevent a battery from freezing, it must be kept in a well-charged condition. The effects of freezing on battery plates are clearly shown in Fig. 413. When a battery freezes, the ice forming in the pores expands and forces the active material out of the plates in chunks.

If it becomes necessary to add water to the battery in cold weather, this should be done just before running the engine. In very cold weather, however, it is better to start the engine and have the battery charging before the water is added. This is done because water, being lighter than acid electrolyte, will remain on the surface of the liquid in the cells until circulated

and mixed by the charging current. If water is added, and the battery is allowed to stand for a time without being charged, there is a possibility that the water will freeze on the surface of the solution, with the result that the jar will crack around the top, causing loss of electrolyte.

291. Cracked Battery Jar.—Indications of a cracked battery jar are: (1) battery box wet with electrolyte on the bottom, (2) low electrolyte level in affected cell, (3) specific gravity below that of the other cells, and (4) the necessity of more frequent filling to keep the electrolyte at proper level. The causes of cracked jars were given in Art. 273. A typical example is shown in Fig. 414. Since the loss of electrolyte from the cell may result



(A) (B)

FIG 413 —Plates from frozen battery. (A) Positive. (B) Negative.

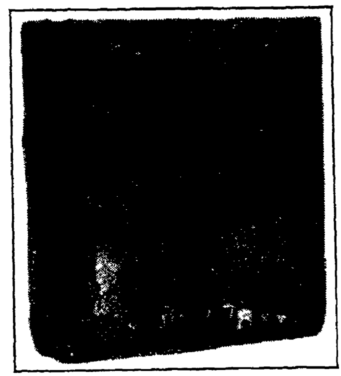


FIG 414 —Cracked jar due to buckled plates.

in open-circuiting the battery, over-sulphation of the affected cell plates, and usually injury to the rest of the battery and destruction of the battery box and container due to the action of the acid, any cracked jar should be investigated and remedied at the first indication. It cannot be repaired, consequently it must be replaced.

To Remove the Jar.—In many cases the jar is held in the box by sealing compound. If so, it can be removed best without damage by first heating the inside of the jar thoroughly with live steam or hot water. After about 5 min. heating, the compound will be melted enough and the rubber jar rendered sufficiently pliable so that it can be drawn out of the box without cracking. This may be done by pulling straight up slowly with a steady pull, holding opposite edges of the jar with suitable pliers.

292. To Test Jar for Cracks.—If a jar is cracked, but the crack is not visible to the eye, it may be located by using high-voltage

test leads from a spark coil as explained for testing high-tension insulation, Art. 192. Remove the jar from the box and fill it with water, making sure that the outside of the jar is thoroughly dry and free of acid. Then, with one high-voltage test point in contact with the water in the jar, explore the outside of the jar with the other. In case a crack exists, the high-tension spark will jump through the crack in the jar instead of across the safety gap.

Another effective method of testing for a cracked jar is to submerge the jar filled with either electrolyte or salt water to within ½ in. of its top in water to which a little common table salt has been dissolved; then test between the solutions inside and outside of the jar with a 110-volt test lamp, as shown in Fig. 415. Care should be taken that the upper edge of the jar is dry and free from acid to prevent creepage of current. If a crack exists, the lamp filament will glow. A still more reliable test could be made using a high-range voltmeter connected in place of the lamp.

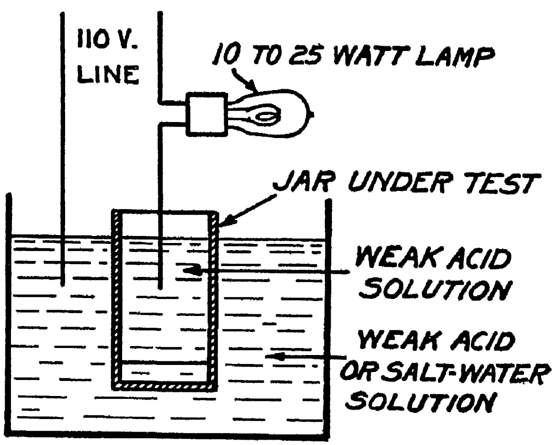


FIG. 415.—Method of testing for cracked battery jar using 110-volt test lamp.

293. Rebuilding the Battery.—In case the battery operation is affected by internal troubles, such as defective separators, high sediment, broken jars, etc., it will be necessary to rebuild the cells so affected, and generally the entire battery. If possible, the battery should be fully charged before it is taken apart in order to drive the acid out of the plates into the electrolyte. This, however, may be impossible in bad cases of broken-down insulation.

To Disassemble the Battery.—The first step in disassembling the battery is to remove the connecting links and terminals. This may be done, if they

are of the burned-on type, by drilling about half way through the burned-on portion of the post connection, as shown in Fig. 416. For this purpose use a metal working drill of ½- to ¾-in. diameter, depending upon the size of the post. Make sure that the vent plugs are in place to prevent the lead cuttings from entering the cells. The connectors can then be removed with a pair of gas pliers without difficulty.

To take out the elements, the sealing compound around the top of each cell, which seals the cover with the top of the jar to prevent leakage, must first be heated. This is usually done by injecting live steam under several pounds' pressure into each cell through the vent plug opening for from 5 to 10 min. Another method is to place the battery in an oven, which is heated by a gas burner or electric heating coils located above the battery, so that it heats principally the top of the cells. This softens the compound so that,

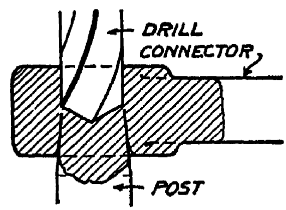


Fig 416.—Method of drilling to remove post connector.

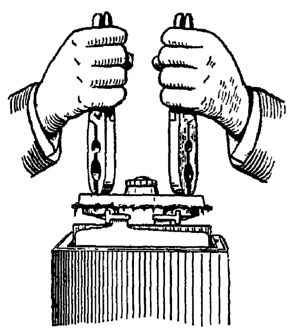


Fig 417.—Method of withdrawing element from cell after sufficient heating.

with the aid of two pairs of pliers holding to the two cell posts, as in Fig. 417, the entire element, including cover, can be drawn out of the jar. If necessary, the sealing compound can be cut loose or removed from around the covers with a heated screwdriver or putty knife. To permit draining and inspection of the plates the elements may be drawn out and rested in a slanting position on the top of the jars. Further procedure will depend upon conditions found.

Reassembling the Battery.—Before assembling the battery, each cell may receive its approximate amount of electrolyte, which will fill the jars one-fourth to one-third full, or it may be added after the battery is assembled. In assembling the elements, care should be taken to arrange them according to polarity, so that the positive and negative terminals will be in proper position for connecting the cells as intended, usually in series—positive to negative. If the covers have not been disturbed or broken, the elements, with covers in place, will usually fit down into position ready for resealing. They can then be sealed into place by adding enough melted compound to fill the spaces around the covers, as in Fig. 418, and passing the flame of a torch back and forth over the tops of the cells, as in Fig. 419, until the

new and the old compound have melted and run together, giving the top of each cell a neat finished appearance and at the same time sealing it against leakage.

The connectors and terminals may then be "burned on" as in Fig. 420, using an oxy-acetylene or hydrogen torch, Fig. 421, intended for lead-burn-

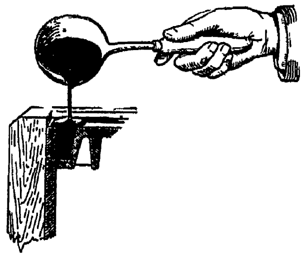


FIG. 418 —Sealing top of battery cell.

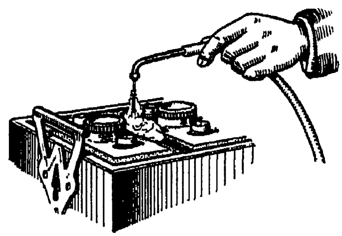


FIG 419.—Using torch to seal tops of battery cells.

ing. (This operation should be attempted only by an experienced battery man, as to do lead-burning well requires considerable practice.) The battery may then be put on charge, it being given the treatment prescribed for abnormal sulphation before putting in service. When fully charged, the electrolyte in each cell should be adjusted to 1.275 to 1.300 specific gravity. A coat of acid-proof paint will give the battery box a finished appearance.

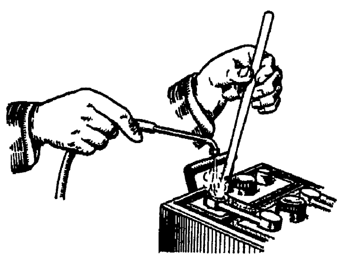


FIG 420.—Method used in burning on cell connector.

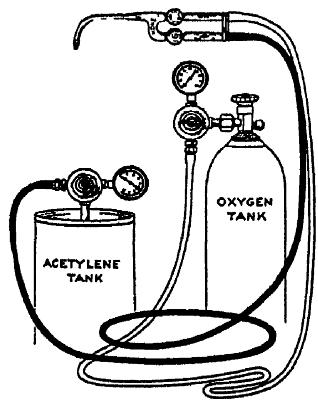


FIG 421 —Oxy-acetylene torch for lead burning.

Caution!—Open flames should be kept away from a battery which is, or has been, charging or discharging, as the gas which accumulates in the tops of the cells is combustible and may explode, wrecking the battery. To avoid danger, remove the vent plugs and blow into each cell before using the torch for lead-burning.

294. General Care of Storage Battery.—Most of the usual battery troubles can be avoided by adhering to the following rules:

1. Keep battery well charged and plates covered with electrolyte to a depth of ¼ in. at all times. Do not over-fill the cells, as the electrolyte expands and may overflow when charging.

2. Add only pure distilled water to replace electrolyte lost through evaporation. Never add acid.

3. Add distilled water to each cell regularly once each week during the summer and once every two weeks during the winter with the car in normal service. During cross-country touring add water each day.

4. Do not allow battery to over-heat. If cell connectors feel warm to the hand, reduce charging rate by burning the headlights.

5. In cold weather, keep battery well charged to prevent freezing.

6. To avoid freezing, do not add water in winter, unless battery is to be charged immediately.

7. Do not propel the car with the starter. If such becomes necessary in an emergency, shift the transmission gears into "intermediate" or "low."

8. Do not over-load the battery by using light bulbs too large, or by adding electrical accessories not intended for the system.

9. Do not leave the car standing with bright lights or ignition switch on for any length of time

10. Do not use the starter excessively.

11. Keep the battery terminals tight and free of corrosion by coating parts with vaseline.

12. Make sure that the generator charges at the proper rate at all times.

13. If the battery tests below 1.210 continually with car in service, have it recharged at a competent service station and check the generator charging rate.

SECTION XVII

LIGHTING EQUIPMENT AND WIRING

295. Automobile Road Lighting.—The lighting equipment forms an important part of every automobile. With the rapid increase in the use of motor vehicles, the ever-increasing average driving speed, and the increasing congestion of city streets and important highways, the providing of adequate and safe road lighting for night driving has become an acute problem. The acetylene lamp has been displaced by electrical equipment because of its greater convenience, and since better illumination and controlling of the light rays are possible.

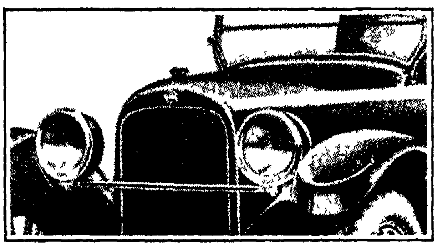


FIG 422 —Typical headlight installation (Nash)

The chief requirements for headlights, Fig. 422, are that the roadway be properly illuminated for several hundred feet ahead of the car as well as the sides of the road, and that the lights do not project glaring rays of light into the eyes of approaching drivers and pedestrians. As a matter of fact, the safety of the driver as well as of other users of the highway depends so much on road illumination that it is now regulated by law in many states.

This section will treat the various types of lighting equipment, and the methods of wiring, while the elements of headlight illumination, road-lighting laws, and the methods of compliance are described in Sec. XVIII.

296. Types of Lighting Systems.—The lighting system as found on most modern passenger vehicles consists of the following component parts:

1. Two headlamps for illuminating the road ahead of the car.
2. Two side lights for marking the width of the car, particularly when the car is parked or driven with the main headlights off.
3. One tail light to illuminate the license number plate and to show a red light to the rear.
4. Dash lights to illuminate the instrument panel.
5. Body lights, such as dome and step lights, for the convenience of the passengers, particulary on closed cars.
6. Special lights, such as spot lights, signal lights, stop and backing lights, which, although not furnished as standard equipment in all cases, are generally installed by the car owner.

The lamps used are necessarily designed to operate at low voltage, namely, 6 or 12 volts—corresponding to the voltage of the battery and generator used—and are wired usually to operate from one control switch located within convenient reach of the driver. Two schemes of wiring have been employed: (1) *the two-wire system,* in which two wires are used to conduct the current to and from each lamp or device, and (2) *the single-wire grounded system,* in which only one wire is run to each lamp or device, the other side of the circuit being grounded, that is, completed through the metal framework of the car. The single-wire system is the more commonly used, as it simplifies the wiring and reduces the cost of construction and maintenance approximately one-half.

297. Headlamp Construction and Mounting.—The principal parts of the typical automobile headlamp are shown in Fig. 423. They are:

1. The lamp housing.
2. The props or bracket for supporting the lamp housing.
3. The reflector.
4. The incandescent lamp.
5. The device for adjusting the incandescent lamp.
6. The front glass.

According to the recommended practice of the S. A. E., the two headlamps should be mounted so that their centers are not less than 32 in. nor more than 42 in. from the ground, the latter distance being the usual construction. The lamps are supported by brackets from either the fender or chassis frame, or both, and are usually sufficiently adjustable to permit a change in the vertical as well as in the horizontal angle of the headlamps. This will permit their horizontal axes to be brought parallel with the axis of the car.

Figure 424 shows the adjustable-type bracket for parabolic-shaped headlamps as recommended by the Society of Automotive Engineers. For methods of headlamp adjusting, see Sec. XVIII.

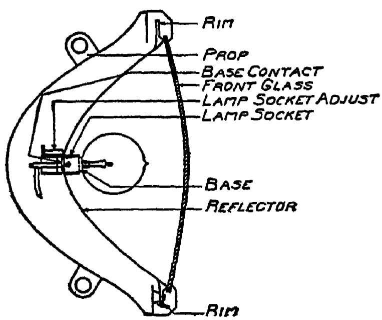


FIG. 423.—Construction of typical head lamp.

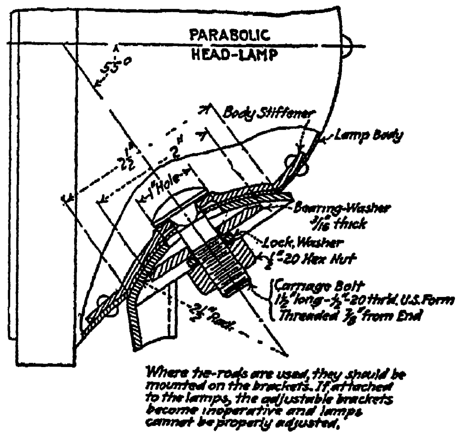


FIG. 424 —Recommended S. A. E head-lamp adjustable mounting

298. Automobile Incandescent Lamps.—The principal styles of lamps used in automobile lighting and the filament forms used are shown in Fig. 425. The lamps may be divided into two classes,

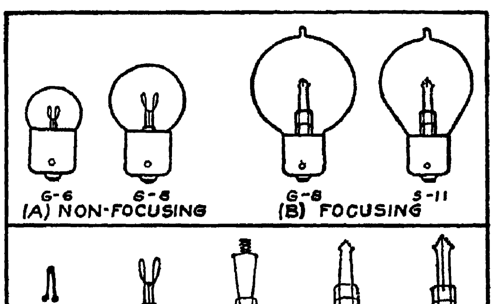


FIG. 425.—(*Upper*) Types of incandescent bulbs for automobile lighting. (*Lower*) Types of lamp filaments.

the *non-focusing* type, as represented by G-6 and G-8, and the *focusing* type, as represented by G-8 and S-11. The letters G and S denote the style of the bulb, namely, *globular* and *pear-shaped*, respectively, while the numbers 6, 8, etc. ordinarily denote

the bulb diameter in eighths of an inch; for example, the type G-6 bulb is globular in shape and 6/8, or 3/4, in. in diameter. The dimensions of the different types of lamps are in accordance with the following table.

Dimension of bulb	(A) Maximum over-all length, inches	(B) Light center length, inches	(C) Maximum distance from top of pin to solder, inches	(D) Variation from axial alignment inches	(E) Variation in light center length, inches
*G-6	1 3/8	5/8	0.299		
*G-8	1 7/8	13/16	0.299		
G-8	1 7/8	7/8	0.299	5/64	±3/32
S-11	2 1/2	1 1/4	0.299	5/64	±3/32

* Non-focusing

The focusing-type bulbs, G-8 and S-11, are used in headlamps, auxiliary headlights, spot lights, and some side lights where it is desired to control the direction of the reflected-light rays; while the non-focusing type is used in side lights, dash lights, tail lights, etc. where the intensity of illumination is not so important. Both types of lamps have the same size bases, the bases being of either the single- or the double-contact type. The single-contact base is used in the single-wire grounded type of lighting system, while the double-contact base is used in the two-wire system.

In the focusing type of bulb it is important that the filament be as concentrated as possible and located at a definite distance from the base. In the larger bulb, type S-11, used in headlamps the nominal light center length *B* (which is the distance between the center of the filament and the inside edge of the base locking pin) is 1 1/4 in., with a permissible variation of 3/32 in., more or less. In the smaller focusing-type bulb, type G-8, which is used for auxiliary headlights, side lights, etc., the light center length is 7/8 in., with the same permissible variation.

In choosing new bulbs to be used in headlights or spot lights, care should be taken to see that the filament in each bulb is properly located in line with the center, since a lamp with a one-sided filament will be difficult to adjust so as to give proper illumination. The lamps are usually furnished in either the vacuum or the gas-filled type, the latter being of greater brilliancy and efficiency. Only those lamps should be used which bear the manufacturers' original ratings stamped on the base. These should include the voltage,

the candlepower, and the current consumption. For example, "21C." or "21 C.P." means 21 cp.; "6-8 V." means 6 to 8 volts, and "2½ A. or 2.5 A." means 2½ amp.

299. Lamp Voltages and Current Consumption.—The normal voltage of electric incandescent lamps used for automobile purposes is in accordance with the number of cells used in the storage battery and with the maximum applied voltage of the generator while charging. For storage batteries of 3, 4, 6, or 9 cells the normal lamp-voltage ratings should be 6-8, 8-10, 12-16, and 18-24 volts, respectively.

The current consumption will depend upon whether the bulbs are of the vacuum-type Mazda or of the nitrogen-filled type. The following table gives the current consumption and voltage rating of the principal sizes of automobile lamps. The vacuum-type bulbs are indicated by type B and the gas-filled type by type C.

Candlepower	Mazda type	Style bulb	Voltage	Amperes	Watts at normal voltage	Watts per candle-power
2	B	G-6	3–4	0 84	2 52	1 26
2	B	G-6	6–8	0 47	2 82	1 41
2	B	G-6	12–16	0 19	2 28	1 14
2	B	G-6	18–24	0 17	3 06	1 53
4	B	G-8	6–8	0 80	4 80	1 20
4	B	G-8	12–16	0 36	4 32	1 08
6	B	G-8(F)	6–8	0 93	5 58	0 93
15	B	S-11	6–8	2 31	13 86	0 92
15	B	S-11	12–16	1 09	13 08	0 87
12	C	G-8	6–8	1 57	9 42	0 78
21	C	S-11	6–8	2 81	16 86	0 80
27	C	S-11	6–8	3.53	21 18	0 78
27	C	S-11	12–16	1.49	17.88	0.66
27	C	S-11	18–24	0.98	17 64	0 65
32	C	S-11	6–8	4.18	25 08	0.78
32	C	S-11	12–16	1.77	21.24	0 66

From this table it may be noted that the type C, or gas-filled bulbs, are much more economical of current than the type B, or vacuum types. The last column of the table shows that the 12-, 21-, and 27-cp. type C bulbs, which

are the most common sizes used in headlights and spot lights, consume approximately 0.8 watts per candlepower as compared with 1.2 watts per candlepower for the type B non-focusing-type bulbs which are used for side, dash, and tail lights.

300. Methods of Dimming.—In order to enable the driver to dim his lights at will, either to prevent glare in the eyes of other users of the highway or to reduce the current consumption of the lights, as when parking, various methods of dimming have been introduced as follows:

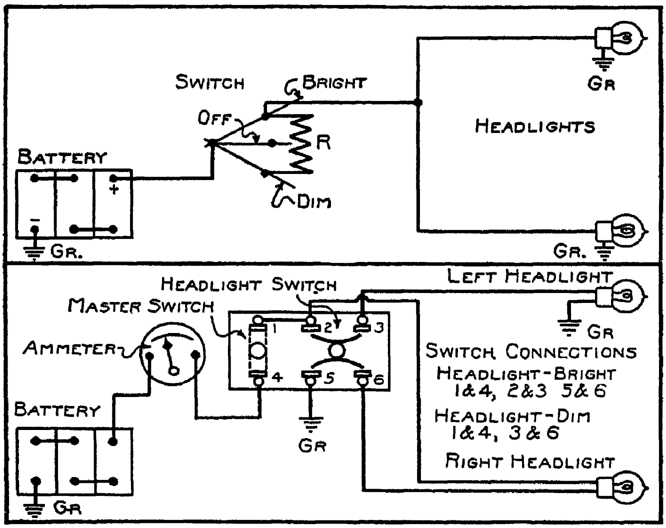


FIG. 426 —(*Upper*) Method of dimming head lights by means of series resistance (*Lower*) Method of dimming head lamp by series-parallel method of wiring.

1. *Series Resistance.*—A common method of dimming is to cut a suitable resistance unit in series with the main headlight bulbs, as illustrated in Fig. 426. By increasing the resistance in the headlight circuit, less current can flow; consequently, the filaments will burn at reduced brilliancy. Since the resistance of the dimming resistance must be in proportion to the size and current consumption of the lamps used with it, care should be taken to decrease or increase its resistance proportionately as the lamp sizes are increased or decreased, otherwise improper dimming will result.

2. *Series-parallel Method.*—The series-parallel method of wiring the headlights is also shown in Fig. 426. With this arrangement the two lights operate in parallel, each at full battery voltage when full brilliancy is desired, and in series, each at half battery voltage, when dimming is desired. Both lamps should be of the same size as to voltage, current consumption, and candlepower; otherwise the smaller one will burn more brightly than the other when connected in series for dimming.

3. *Extra Low-candlepower Bulbs in Headlamp.*—Practical application of the extra low-candlepower bulb in the headlamp is shown in Fig. 427. It consists usually of a 4- or 6-cp. bulb located above the main headlamp bulb and out of focus with the reflector. It operates on full battery voltage,

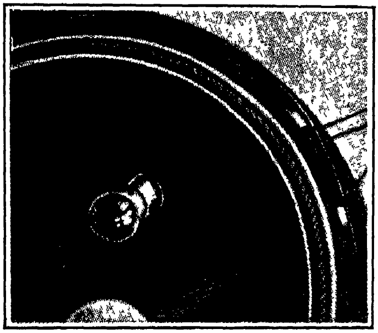


FIG. 427.—Headlight equipped with extra low-candlepower bulb for dimming.

the dimming effect being due to the decreased candlepower and the scattering of the light rays given out when the small bulbs are turned on in place of the main bulbs.

4. *Auxiliary Headlights.*—Auxiliary headlights consist of small lamps located immediately above or below the main headlights as shown in Fig.

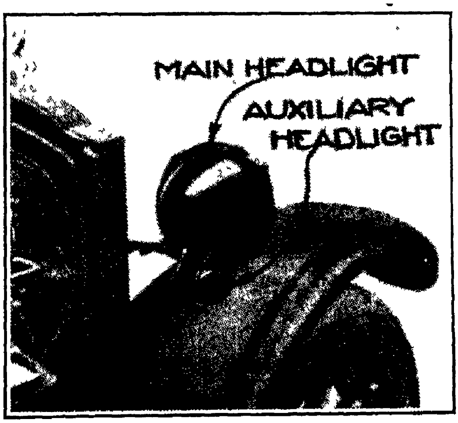


FIG. 428.—Rear view of headlight for Packard "Twin-six" showing auxiliary headlight mounted below main headlight.

428. They are usually equipped with the type G-8, 4- or 6-cp. bulb of either the non-focusing or the focusing type. They operate on circuits separate from the main lamps, as do the side lights. The auxiliary headlamp housing is usually constructed as a part of the main headlamp.

5. *Side Lights.*—Typical side-light construction is shown in Fig. 429. These lights serve to provide reduced road illumination when the main

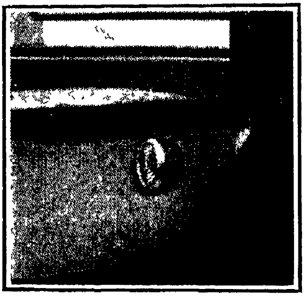


Fig. 429.—Typical side-light installation.

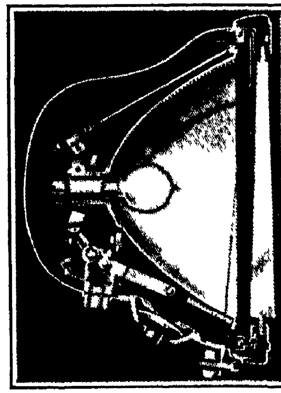


Fig. 430.—Sectional view of head lamp used on Cadillac Eight—dotted lines show tilted position of reflector which is pivoted.

headlights are off and to mark the width of the vehicle, to prevent collision with approaching vehicles. They also serve as parking lights when the car is parked. The side lights are usually equipped with the type G-8, 4-cp. non-focusing bulbs.

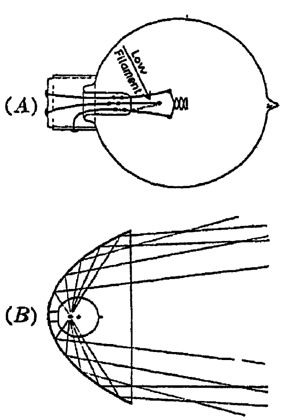


Fig. 431.—(*A*) Two-filament bulb. (*B*) Reflection of light rays from low filament.

6. *Tilting Reflectors.*—The tilting type of reflector, Fig. 430, is used in several prominent cars, for example, the Cadillac, the Lincoln, and the Lafayette. As the name implies, the reflectors are so pivoted, horizontally, that, by the manipulation of a lever on the steering column, both headlight reflectors may be tilted forward, thus lowering the beams of light below the eye level, to prevent glare. This method differs from other dimming methods in that it merely redirects the light rays and does not reduce either the light intensity or the current consumption of the lighting system.

7. *Double-filament Bulbs.*—A typical double-filament bulb is shown in Fig. 431. The bulb is so designed that, when it is mounted in the headlamps, one filament—the coil-type filament, Fig. 431*A*—will be in focus with the reflector, while the low filament will be out of focus and, when operated alone, will cause the lamps to give out reduced illumination, due to the scattering of the light rays, as shown in Fig. 431*B*. This type of bulb has been used extensively on the Ford car.

Note—In installing two-filament bulbs care should be taken to insert the bulb in its socket with the proper side up, otherwise the bulb may burn with the dim filament when it should burn bright.

301. Automobile Light Wiring.—Practically the same wiring is used for automobile lighting circuits as for the primary ignition

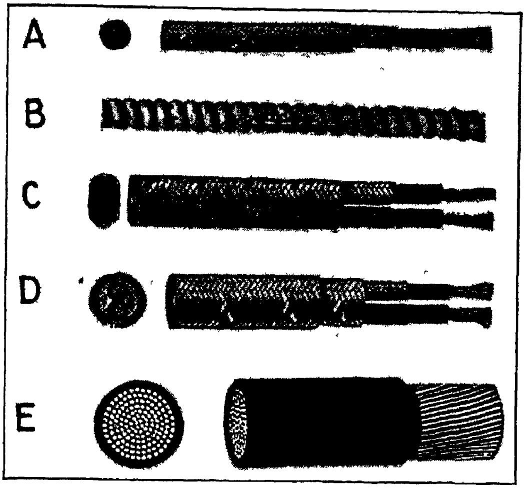


FIG. 432—Types of wire used in automobile wiring. (*A*) Single lighting cable. (*B*) Armored cable (*C*) Two conductor lighting cable—flat. (*D*) Two conductor lighting cable—round. (*E*) Starting cable.

circuits. Both the *rubber-covered-and-braided* and the *armored* cable, types of which are shown in Fig. 432, are used. There is a strong tendency toward the use of armored cable on lighting circuits. This is particularly true where wires are exposed and subjected to chafing on the chassis or body frame. Armored cable, if properly constructed and installed, should give little trouble. It is necessary to strip back the armor sufficiently from the terminals and then solder it down, so that a ground cannot occur at these points.

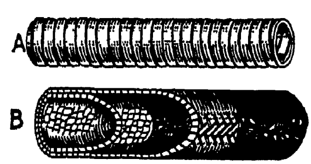


FIG. 433.—Flexible conduits for electric wiring. (*A*) Metallic. (*B*) Circular loom.

Rubber-covered-and-braided or *varnished-cambric-and-braided* cable, protected by flexible metallic conduit, Fig. 433, is generally used. This figure also shows a non-metallic conduit or *loom*, which is also sometimes used. The metallic conduit perhaps gives a more substantial appearance on head- and tail-lamp wires, but it is more expensive than armored cable

both in first cost and in installation. Armored cable is usually unnecessary in the wiring of the instrument board, as the ordinary high-grade rubber-covered-and-braided cables give sufficient insulating protection.

Carrying Capacity of Lighting and Starting Cables.—If it should become necessary to replace any part of the wiring, it is quite important that the proper size wire be used in order that it may carry the load put upon it without undue heating and voltage drop. Safe continuous carrying capacities of the various sizes of cables, in accordance with the S. A. E. specifications for lighting and starting cables, are given in the following table:

Nominal size A.w.g.	Circular mils (nominal)	Continuous carrying capacity, amperes	
		Rubber-covered-and-braided	Varnished-cambric and-armored cable
16	2,583	6	8
14	4,107	15	18
12	6,530	20	22
10	10,383	25	27
8	16,510	35	45
4	41,741	70	80
2	66,371	90	110
1	83,693	100	140
0	105,535	125	180
00	133,077	150	210

It will be noted that the armored cable permits somewhat greater carrying capacities than the rubber-covered-and-braided.

Soldering.—When soldering copper cables, which have rubber-covered insulation, a good quality of soldering paste should be used instead of muriatic acid, which is sometimes used, because the acid will attack the rubber and destroy the insulation.

302. Wiring Methods.—It is good practice to consolidate lighting and low-tension wires wherever possible and to braid them together or run several wires through one piece of conduit. This method is economical and convenient and tends toward rugged and safe installation. If the proper wire is used and the individual wires are assembled in a workman-like manner, installations of this sort give little or no trouble from the repair-shop standpoint. This use of assemblies, or wiring harnesses, as they are often called, is admirable from a car-assembly standpoint. Since the wiring harnesses are formed up on a bench, the result is uniformity

and careful workmanship, and a more satisfactory wiring job. The different wires of the cable usually have different colored insulation, so as to simplify the tracing of the wires through the cable.

Junction and Fuse Blocks.—The usual method of joining the wiring of the chassis to that of the body is by junction blocks, Fig. 434, located on the cowl board or side frame, thus avoiding splicing and soldering of the wires. With this arrangement, the body and the chassis of a car may be wired separately, and the wiring quickly joined by means of the terminals provided when the body and the chassis are assembled.

The junction block, in some cases, may also include the fuses for protecting the individual circuits, as shown in Fig. 435. Where fuses are used, each

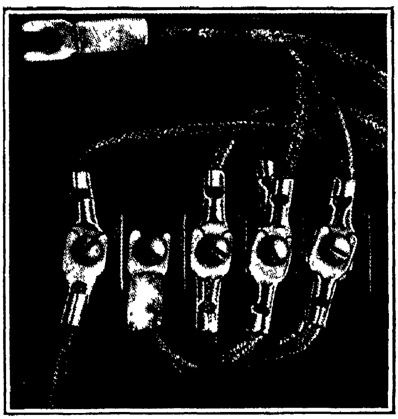


FIG. 434 —Junction block without fuses (Ford).

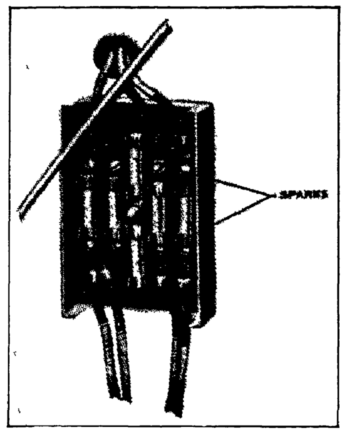


FIG 435.—Junction block with fuses (Essex).

circuit should be protected by a separate fuse rather than having one fuse control several circuits. With each circuit fused separately, it is easier to locate trouble and, when circumstances require, it is possible to operate the car with one circuit out of commission.

Capacity of Fuses.—To insure proper operation and protection of the circuits, each fuse must make a tight, clean contact in its clips and be of the proper capacity. Lighting fuses should usually be of at least 10-amp. capacity when used in individual lighting circuits and 20- to 30-amp. when a single fuse is used to protect all the lighting circuits. The capacity of the fuse in amperes is usually stamped on one end of the fuse.

303. The Delco Protective Circuit Breaker.—The Delco circuit breaker is a protective device or relay connected in the main lighting circuit to take the place of fuses. A typical installation

on the back of the lighting switch is shown in Fig. 436. It consists of a single-wound coil with a vibrator in series, the contacts of which are normally held closed under spring tension. The strength of the spring is such that the normal current consumed by the lights will not affect the vibrator; however, should a ground occur on one of the light wires, causing the current to increase over the predetermined amount of, say, 25 amp. for which the vibrator is set, the magnetic pull on the vibrator arm will be sufficient to overcome the tension of the spring and the circuit breaker will continue to vibrate and give a warning sound until

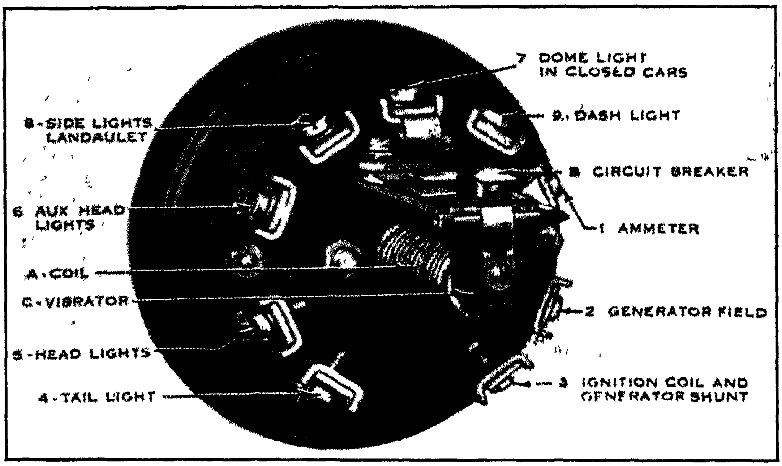


Fig. 436.—Rear view of Delco lighting switch showing installation of protective circuit breaker.

the ground is removed. Although the device requires 25 amp. to start it vibrating, once started, a discharge of only 5 to 7 amp. will pass through it, thus protecting the wiring against overheating and the battery against rapid discharge. By this method of protection, when the cause of trouble is removed, the circuit breaker will remain closed and the car can proceed without resorting to the installation of makeshift fuses, which is always dangerous.

304. Types of Lighting Switches.—Typical lighting switches, including their circuits, which have been used for automobile lighting are shown in Figs. 437 to 442, inclusive. The characteristics of each switch are as follows:

Figure 437 shows the early type of Gray and Davis switch which was used on many cars employing the two-wire system. It is of the snap-switch type, having four positions, "Off," "Dim and Rear," "Bright and Rear,"

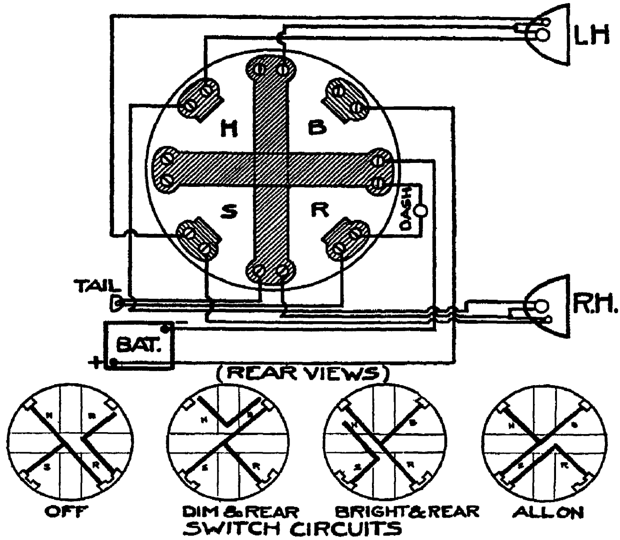
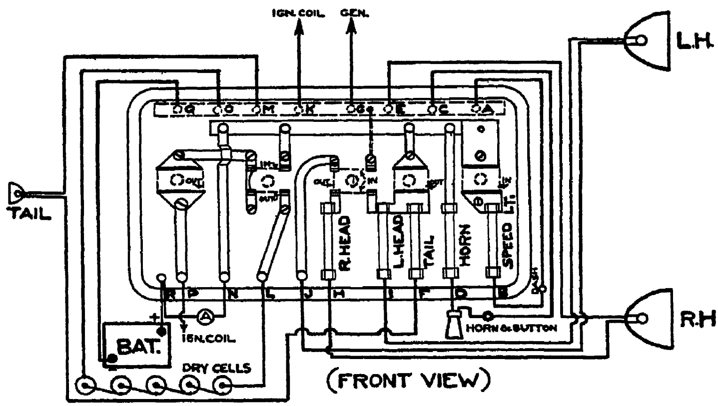


FIG. 437.—Circuit diagram for early type Gray & Davis snap type lighting switch.



NOTE: DOTTED LINES INDICATE CIRCUITS WITH BUTTON PUSHED IN OR PULLED OUT

FIG. 438.—Circuit diagram of Cutler-Hammer lighting switch used on 1915 Studebaker.

and "All On," respectively, the circuits being as shown. This switch is found on the King Eight.

Figure 438 shows the Cutler-Hammer switch used on the 1915 Studebaker. This is a pull-button switch of the two-wire type, in which the headlights are dimmed by connecting them in series.

Figure 439 shows the circuit diagram of the Connecticut lighting and ignition switch used widely on the Overland car. It is of the pull-button

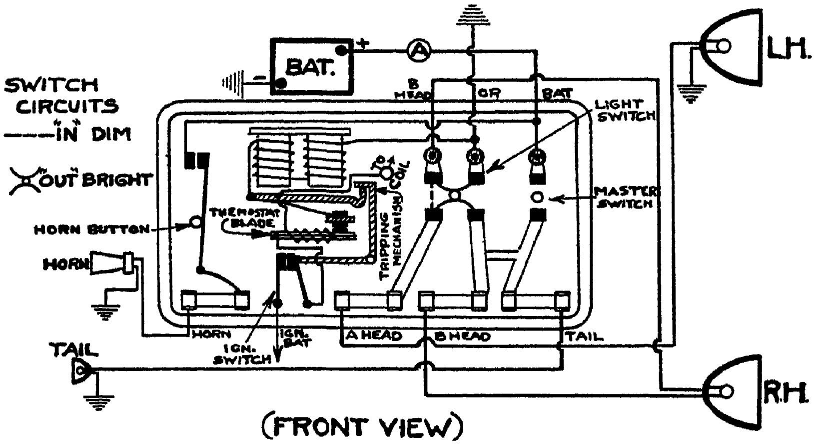


Fig. 439.—Circuit diagram of Connecticut lighting switch—steering post type for Overland

type, the switch being mounted on the side of the steering column. The headlights are connected in series for dimming.

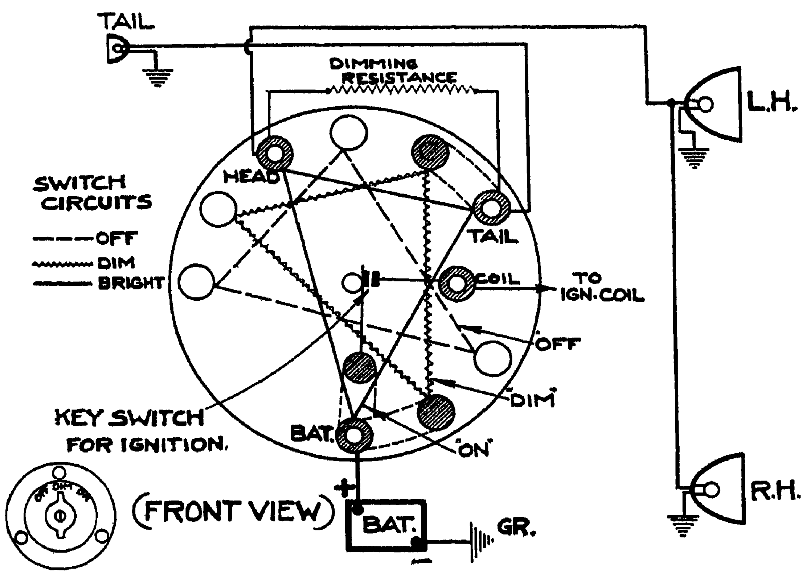


Fig. 440.—Circuit diagram of Clum lighting switch as used on Dodge car.

Figure 440 shows the circuits of the Clum lighting and ignition switch as used on the Dodge car. The lighting part of the switch is operated by the

turning of the handle, while the ignition is operated by a key. The switch is of the single-wire grounded type and has three positions, "Off," "Dim," and "On," as shown in the lower left-hand view. Headlights are dimmed

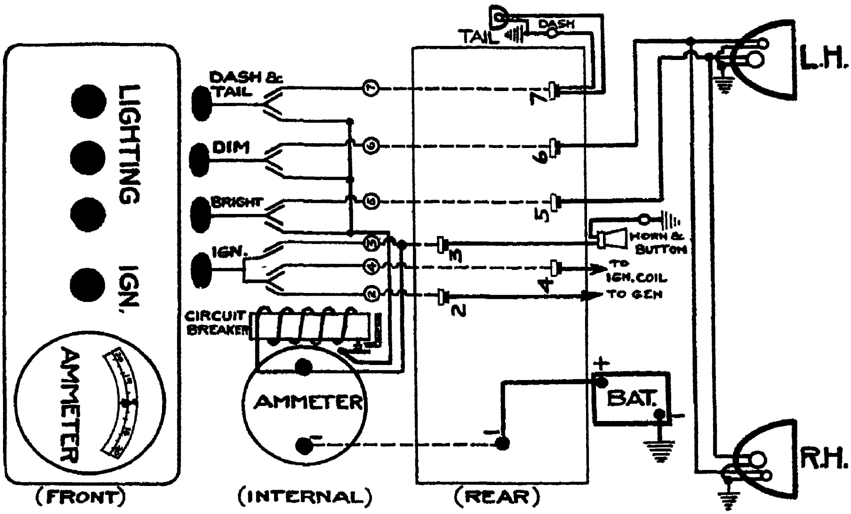


FIG. 441 —Circuit diagram of early Delco pull-button type lighting switch.

by passing the headlight current through the resistance unit located on the back of the switch when the switch is turned to the "Dim" position.

Figure 441 shows the circuit diagram for the Delco pull-button type of lighting and ignition switch used widely on cars prior to 1919 With the

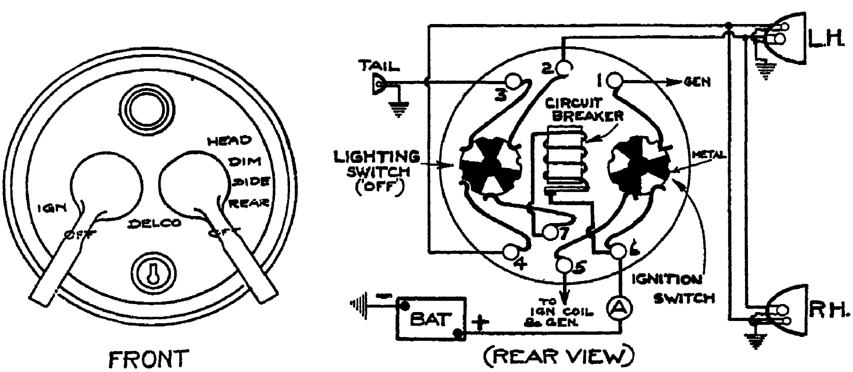


FIG 442.—Circuit diagram of typical Delco round type lighting switch. Rear view shown in Fig. 436.

method of wiring as shown, dimming is effected through the use of low-candlepower bulbs mounted either in the same lamp with the main bulbs, but out of focus with the reflector, or as small auxiliary headlamps mounted above or below the main lamps. In some installations a resistance unit was

mounted on the switch, connected between terminals Nos. 6 and 7, for dimming the main headlights. A circuit breaker is connected in the main lighting circuit, which takes the place of fuses as a protective device.

Figure 442 shows the round type of Delco switch used widely since 1910. The circuits are as shown at the right. As will be noted, the switch is of the single-wire grounded type, the headlights being dimmed through small bulbs located either in the headlamps or in the side lamps. A circuit breaker is mounted on the back of the switch and connected in the main lighting circuit, thus serving as a protective device.

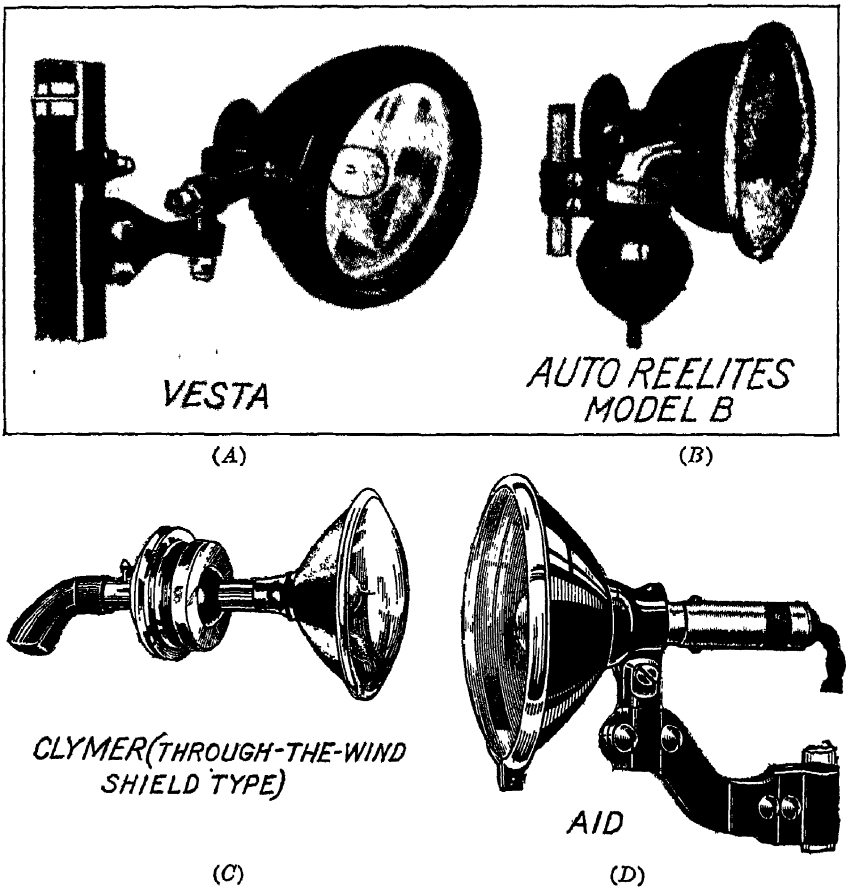


FIG. 443.—Types of spot lights.

305. Spot Lights.—The spot light consists of a focusing-type lamp, similar to but smaller than the headlight. It is usually mounted at one end of the windshield and can be manipulated at

will by the driver. In some cases it is installed to operate through the windshield, which makes it very convenient in a closed car. Types of spot lights are shown in Fig. 443.

The spot light is usually equipped with a type C bulb of 21 to 32cp. and wired so that it can be turned off and on at the lamp independent of the regular lighting switch. In order to comply with the laws in some states, it must be equipped with a special bracket which will confine the movement of the lamp, so that, within an angle of 30 deg. to each side of the car axis, the light will not strike the road more than 75 ft. ahead of the car, thus preventing a glare to approaching vehicles. Outside of this restricted angle the spot light can be elevated to any height to permit reading of road signs, etc.

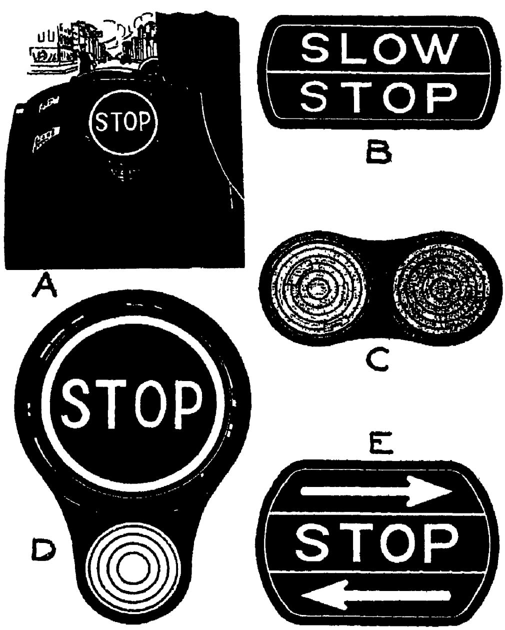


FIG. 444.—Types of stop and signal lights.

306. Signal Lights.—As a safety measure, to prevent rear-end collisions in congested traffic, various forms of stop and direction signals have been devised. The simplest form of signal, and the one in most common use today, is the so-called *stop* signal, illustrated in the upper left corner of Fig. 444. This simply

indicates that the driver of the car carrying the signal is applying his brakes and is slowing down. The signal is operated automatically; probably the most common form of control is by the brake pedal closing a switch in the lamp circuit, which normally remains open. This automatic control relieves the driver of the necessity of extending his arm or of manually operating a signaling device when making a stop, which is often so sudden as to require his entire attention. A cross-sectional diagrammatic view of a stop signal of good design is shown in Fig. 445.

For initial installation by the car manufacturer, the stop signal is often combined in one housing with the tail light, as shown in the lower left corner, Fig. 444, although the two units operate independently of each other. Another arrangement is the combination of a stop signal with a *parking* lamp in one housing.

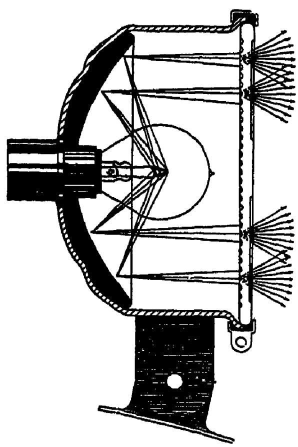


FIG. 445.—Sectional view of typical stop light.

The stop signal, while of great value, does not in all cases give a complete indication of the driver's intentions. It is desirable that, when a turn is contemplated, a signal of the intended direction be given to the driver of the car following. This is readily accomplished by the *stop* and *direction* signal shown in the lower right corner, Fig. 444. Either arrows or the words *right* and *left*, illuminated by the lamps within the housing, indicate the direction of the intended turn. These may be combined in one unit as shown, or may be separated, one arrow being sometimes mounted on each rear fender.

Operation of Signal Lights.—In order that the driver may be assured that the rear signal light is operating, a small indicator lamp on the dash, which is connected so as to flash on with each operation of the signal light, is sometimes used. The signal light should be 21 cp., while the indicator lamp need only be 2 cp. This means that they cannot be operated in series, as can the dash and tail lights, having equal resistances and candlepower, since the small lamp would quickly burn out. Therefore, the lamps are connected as shown in Fig. 446. As the switch is operated, the movable member *a* passing to the position *b* momentarily places the two lamps in series. The 2-cp. lamp, having the higher resistance, is lighted to practi-

cally its full brilliancy, although the current at this time is insufficient to light the larger signal lamp. As the switch action is completed by the movable member passing to position *C*, the indicator lamp is short-circuited and

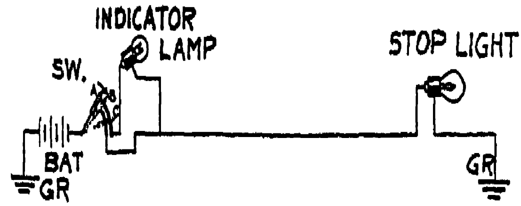


FIG. 446.—Method of connecting indicator lamp in circuit with stop light.

goes out, and full voltage is impressed on the signal lamp, which then lights at full brilliancy. This process is repeated in the reverse order as the switch arm *a* moves back to its original position. A flash of the indicator lamp is thus obtained each time the signal is turned on and off.

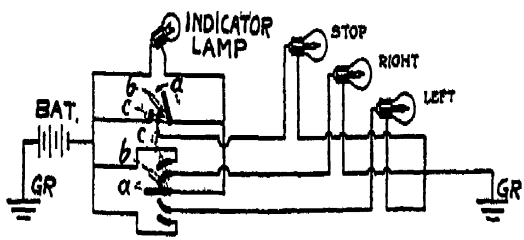


FIG 447—Circuit diagram for adaptation of the series-flasher system to signals using several lamps.

With a slight change, this indicator system can be readily applied with equal effectiveness to a multiple signal system comprising direction as well as stop signals. Figure 447 shows the connections for such a system.

SECTION XVIII

ELEMENTS OF HEADLIGHT ILLUMINATION

307. Primary and Secondary Light.—The light rays given out by any light source—for example, incandescent lamps—which produce illumination may be divided into two kinds, namely, *primary* and *secondary* rays. The primary light rays pass directly from the light source to the object being illuminated, while the secondary rays are reflected. The light, for example, given out by the sun is primary light, since the light rays are emitted directly from the light source; while that which is given out by the moon is secondary, since it merely reflects the sun's rays. The light given out by an incandescent lamp without a reflector of any sort is primary light, but if the lamp is surrounded by a reflector, as in a headlight, the light given out will be comprised of both primary and secondary rays, the latter being those reflected by the polished surface of the reflector. The controlling of the secondary light rays constitutes the principal problems in road illumination, as these are the rays which tend to produce glare thus blinding approaching drivers and pedestrians.

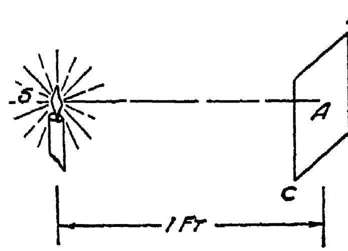


FIG. 448.—The illumination at *A* is one foot-candle.

308. Units for Measuring Illumination.—The principal units which have been adopted for the measuring of the intensity of light and illumination are:

The Candle.—The unit for measuring the intensity of light is called the *candle*, named after the tallow candle which was used for producing illumination before the electric-light bulb came into use. Thus, the present-day lamp bulbs are rated according to the illumination which they give out in comparison with the light given out by a standard tallow candle. For example, when a lamp bulb is said to give 21 cp., it means that its intensity of light is equal to that of a group of 21 standard candles.

Candlepower.—The candlepower of a light is the measure of strength of the source to produce illumination in a given direction.

Mean Spherical Candlepower.—The mean spherical candlepower of a lamp is the average of all the candlepowers in all directions about that lamp. Thus, if a source gives 1 candle in every direction it will have a mean spherical candlepower of 1, or if a source gives off various candlepowers in different directions, but if the average of all these candlepowers is 1, this source would have a mean spherical candlepower of 1.

The Foot-candle.—The foot-candle is the unit for measuring the intensity of illumination. It is equal to the illumination produced at a point on a plane one foot distant from a light source of one candlepower, the plane being perpendicular to the light rays at that point. In Fig. 448, if the source *S* gives an intensity of 1 candle along the line *SA*, and if *A* is 1 ft. distant from the source, the intensity of illumination on the plane *CD* at the point *A* is 1 ft.-candle.

The intensity of illumination, measured in foot-candles, is the unit of measurement most commonly used in the subject of road lighting. In practice it is measured by the use of an instrument called a *photometer* or *foot-candle meter.*

309. The Effect of Light Intensity and Distance upon Illumination.—The intensity of illumination on an object depends

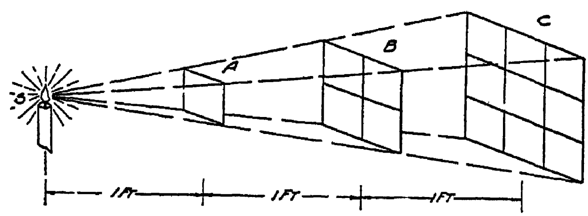


FIG. 449.—Showing how the illumination on a surface varies inversely as the square of the distance from the source to the surface.

upon the intensity of the light source and the distance between the light source and the object illuminated. It also depends upon the color and other characteristics of the object upon which the light falls. The intensity of illumination on a surface, as indicated by the foot-candles, should not be confused with the appearance as regards brightness of the surface. A gray surface lighted to an intensity of 1 ft.-candle will not appear as bright as a white one, as a greater proportion of the light falling upon the gray surface is absorbed and lost. *The brightness of an object, therefore, depends both upon the intensity of illumination on it, that is, foot-candles, and the per cent of light that it reflects.*

It will be readily seen by means of Fig. 449 that *the intensity of illumination on a plane diminishes as the distance between the plane and the light source is increased.* For example, assume planes *A*,

B, and *C* to be at distances of 1, 2, and 3 ft. from the light source. The same beam of light which intercepts a plane of 1 sq. ft. at *A*, a distance of 1 ft., will intercept a plane 2 ft. square, or 4 sq. ft., at *B*, a distance of 2 ft. from the light source. At *C*, a distance of 3 ft., it will intercept an area 3 ft. square, or 9 sq. ft. Thus, the area of the planes intercepted by the same light beam increases in proportion to the square of the distance. On the other hand, the intensity of illumination on planes *A*, *B*, and *C* will decrease in proportion to the square of the distance; that is, the average intensity of light on *B* will be one-fourth of the intensity at *A*, and on *C* it will be one-ninth of the intensity on *A*.

310. The Spectrum.—White light is composed of many colors blended together, as is proved when light is made to pass through a prism of glass, when it produces a rainbow of colors, called the *spectrum*. The number of colored tints in the spectrum is so great that even when they are separated by means of a prism they form a continuous blend of color. There are seven principal colors in the spectrum, known as the simple or primary colors. They are red, orange, yellow, green, blue, indigo, and violet.

When a white light passes through a colored glass, all the rays, except those which are of the same tint as the glass, are absorbed. For example, in an amber-colored headlamp lens, only the amber, or yellow-tinted rays, of the white light produced by the electric-light bulb pass through the lens.

311. Interference of Light.—A ray of light will travel along a straight line indefinitely unless it meets with interference. Such interference may be in the nature of *absorption*, *refraction*, *reflection* or *diffusion*.

Absorption is the interference of light through the absorbing of the light rays by the medium through which it passes or by the object upon which it impinges. A beam of light, for example, may be absorbed by passing through a smoky atmosphere, through a piece of smoked glass, or by meeting a black, opaque body.

Refraction is the bending of the light rays when they pass from one medium to another of greater or less intensity, as from air to water, or from air to glass. The refraction of light may be illustrated by the apparent bending of a stick partly immersed in water, the stick appearing to be broken or bent at the surface of the water.

Reflection is the throwing back or redirection of the light rays by a reflecting surface. Light, for example, is reflected by a polished metal or mirrored surface.

Diffusion is the breaking up of a light beam and the spreading of its rays in all directions by the medium through which it passes.

All these methods of light interference have been utilized in the construction and operation of automobile headlights.

312. Projection of Light.—The simplest method of controlling light rays is by reflection. This principle is used in the design of the headlamp reflector. A ray of light having a direction *S-A*, Fig. 450, on striking a polished metal surface is reflected in the direction *A-B*, so that the angle *Y*, called the *angle of reflection,* is equal to the angle *X*, called the *angle of incidence.* With a

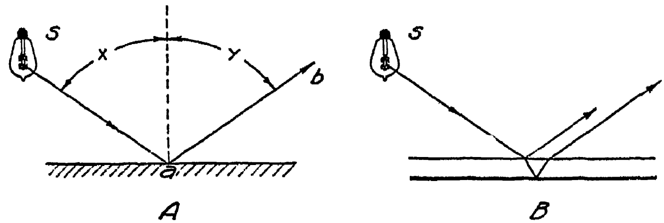


FIG. 450.—(*A*) Reflection from polished surface. (*B*) Reflection from mirrored surface.

perfectly smooth reflecting surface, practically no light is reflected in any other direction.

313. Headlamp Reflectors.—The reflector used in the automobile headlight is made as nearly as possible in the form of a true paraboloid of revolution, having a fixed focal length of 1¼ in. A *paraboloid* is the curved surface obtained by revolving a curve known as a *parabola* about its axis. The parabola is obtained by cutting a section *A-B* off a right-type cone parallel to a tangent plane *C-D*, as in Fig. 451. The curved edge formed by cutting off this section is the shape of a true parabola, the characteristics of which depend upon the height of the cone and the diameter of the base. There is a definite point along the axis of the lamp reflector—usually 1¼ in. from the vertex—called the *focal point* or *center.* If the light could be concentrated at this focal point, all light rays from it, upon striking the reflecting surface, would be reflected in lines parallel to the axis of the reflector, as in Fig. 452*A*. Thus, in a lamp which is in focus, the center of the lamp filament should coincide as nearly as possible with the focal point.

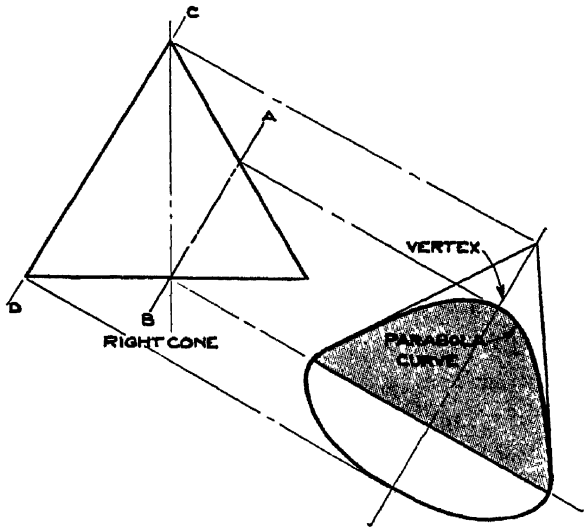


FIG. 451.—Formation of parabola curve from cone.

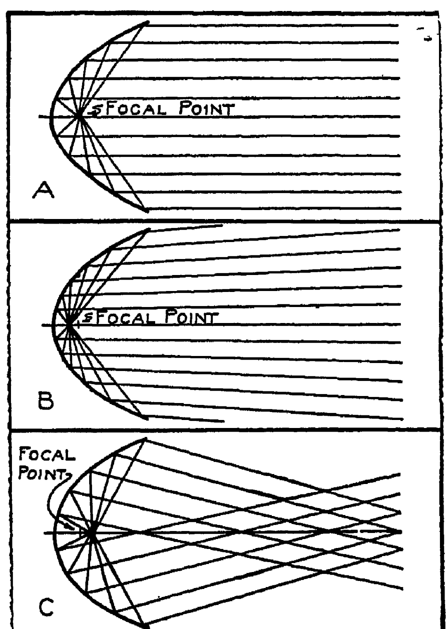


FIG. 452.—(*A*) Reflection of light rays with lamp filament at focal center. (*B*) Reflection of light rays with light source behind focal center. (*C*) Reflection of light rays with light source ahead of focal center.

314. Principles of Headlight Focusing.—If all the light could be concentrated at the focal point, the reflected light rays would be parallel, or approximately so, to the axis of the reflector. If the filament of the incandescent bulb, however, is not in this focal center, but is ahead or behind it, the reflected light rays will not be parallel to the axis of the reflector. With the lamp filament back of the focal center, the light rays will be reflected in a spreading beam, as shown in Fig. 452*B*. With the lamp filament ahead of the focal center, the light rays will be reflected in a diverging beam, the rays crossing at a point ahead of the reflector, as shown in Fig. 452*C*. Thus, in Fig. 452*B*, with the bulb behind the focal center, the upper half of the reflector reflects the light rays upward, while with the bulb ahead of focal center, as in Fig. 452*C*, it reflects them downward.

315. Means for Focusing Headlights.—Four methods for adjusting the position of the headlight bulbs to obtain the proper

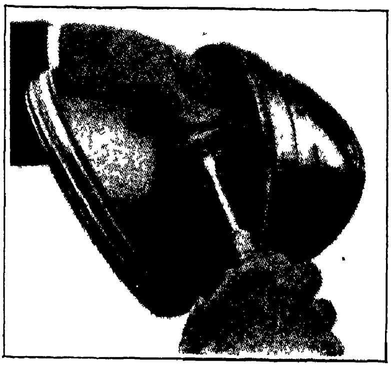


Fig 453.—Headlight with inside bulb adjustment.

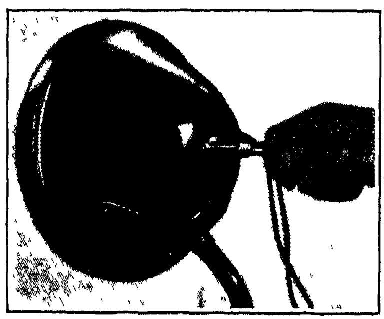


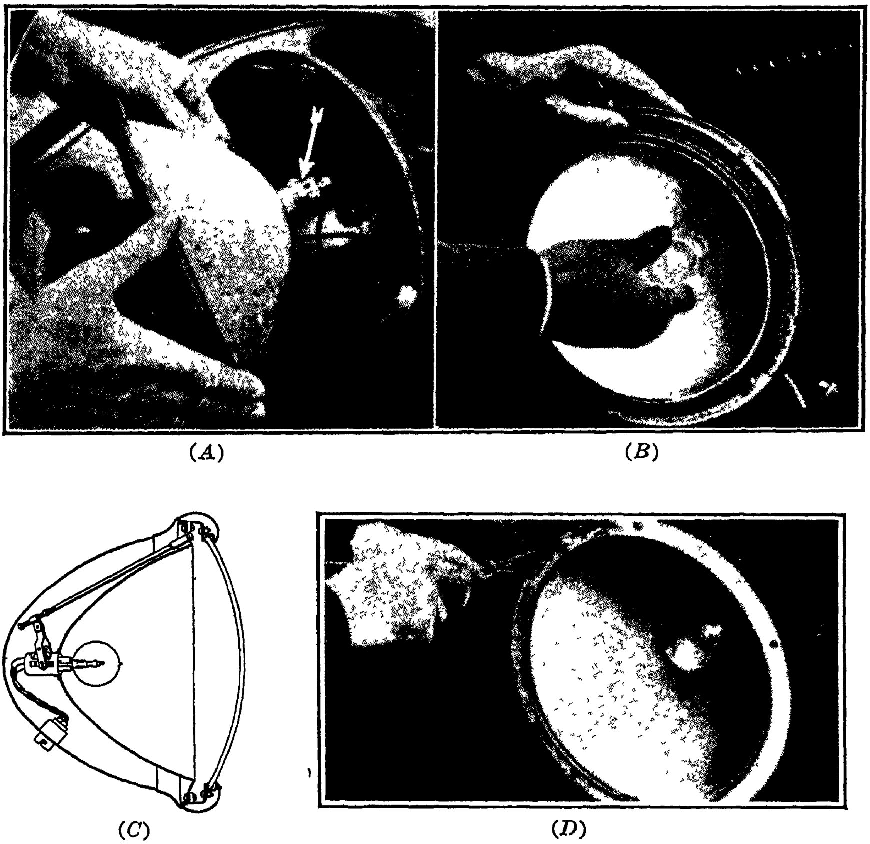
Fig. 454.—Method of focusing head light with outside adjustment

illumination are illustrated in Figs. 453, 454 and 455. These figures illustrate the *inside adjustment*, the *outside adjustment*, the *bulb adjustment*, and the *rim adjustment* for focusing the lamps, respectively. In all these methods the object is to move the lamp bulb forward or backward in order to put the filament in the proper focal position. The operation of each method is as follows:

Inside Adjustment.—In the inside method of adjustment, Fig. 453, the position of the bulb is fixed by a set screw which binds the bulb socket. In order to get at the adjustment, the reflector must be removed.

Outside Adjustment.—In the outside adjustment method, Fig. 454, a screw or thumb nut is located back of the lamp case, the turning of which adjusts the bulb forward or backward in the reflector. This method does not require the removal of the front glass or reflector.

Bulb Adjustment.—In the bulb method of adjusting, Fig. 455*A*, the bulb socket is held in place by a friction device. Adjustment can be made by



(*A*) (*B*) (*C*) (*D*)

Fig. 455.—(*A*) Head-lamp with reflector removed showing friction device for adjusting bulb-position. (*B*) Method of focusing bulb having friction type adjustment. (*C*) Sectional view of typical clamp with rim adjustment (*D*) Method of focusing headlight having rim adjustment of bulb.

simply removing the front glass and forcing the bulb backward or forward with the fingers. Care should be taken to cover the knuckles with a handkerchief, to prevent marring the reflector.

Rim Adjustment.—One type of rim adjustment is shown in Fig. 455*C*. The position of the bulb can be adjusted by removing the front glass and turning the adjusting screw to the right or to the left with a screwdriver.

In most cases turning the screw to the right moves the bulb toward the reflector, while turning it to the left moves it away from the reflector.

316. Effect of Bulb Position upon Light Distribution.—The distribution of the light rays from automobile headlamps may be readily observed by driving the car to a place where the light from the headlights will be thrown upon a wall or other vertical surface approximately 25 ft. from the vehicle. In moderate darkness the pattern of light produced by either headlight will be shown by covering up or disconnecting one light at a time. If the lamps are equipped with special lenses or non-glare devices of any kind, these should be removed, so that the exact bulb positions may be determined. Four bulb positions have been universally defined and adopted to facilitate headlight adjusting. In fact, most anti-glare-type lenses and devices are designed for a definite setting of the bulb, the bulb adjustment being usually referred to by number. They are as follows:

Focal Adjustment No. 1.—No. 1 bulb adjustment is obtained when the patch of light made by the beam is of minimum diameter, as in Fig. 456. The center of the lamp filament will then be in focus, that is, with half of the filament in front and half in back of the focal point of the reflector.

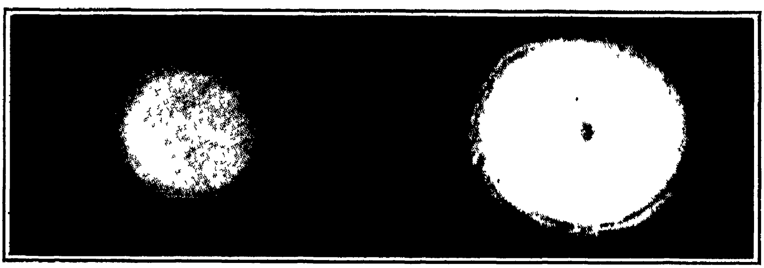


FIG. 456.—Light produced with lamp filament in No. 1 adjustment.

FIG. 457.—Light from headlight in No. 2 or No. 4 adjustment. Dark spot just appearing.

Focal Adjustment No. 2.—By drawing the lamp backward from No. 1 adjustment, the patch of light will become larger and larger, until finally a dark spot appears at its center, as in Fig. 457. When this spot is on the point of appearing, the lamp is said to be in No. 2 adjustment. If the bulb is farther back than the No. 2 adjustment, the light produced will be as shown in Fig. 458.

Focal Adjustment No. 3.—The lamp is considered to be in No. 3 adjustment when it is intermediate between positions Nos. 1 and 2; also, the patch of light will be intermediate to those produced by adjustments Nos. 1 and 2.

Focal Adjustment No. 4.—In No. 4 adjustment the lamp is pushed ahead of focal center, or position No. 1, until a black spot is on the point of forming in the center of the patch of light, as in Fig. 457.

In case the headlamp is so constructed that it is not easy to tell whether the lamp is being moved forward or backward, No. 2 position can be distinguished from No. 4 by blowing a cloud of smoke into the beam directly in front of the headlamp. If the rays of light are seen to diverge or spread as they leave the reflector, the adjustment is No. 2; if they converge and cross, it is No. 4.

In general, moving the light source either forward or backward along the axis of the reflector changes the spread of the beam. Moving the light source up from the axis throws the beam down and moving it down throws the beam up. In like manner, moving the light source to the right throws the beam to the left, and *vice versa*.

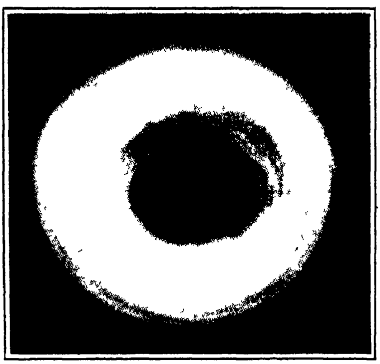
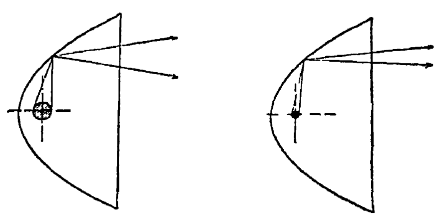


FIG. 458.—Light from headlight with bulb adjusted either too far behind or too far ahead of focal center.



(*A*) (*B*)

FIG 459.—(*A*) Reflection of light rays from large filament. (*B*) Reflection of light rays from small filament.

317. Importance of Accuracy in Filament Construction.—Lamp filaments which are not well concentrated and accurately located in the bulb cannot be focused so as to give a concentrated beam. The effect on the spread of the beam from large and small filaments is shown in Fig. 459. Tests have shown that, if the filament of an automobile headlight lamp is located but 1/16 in. from the focal point of the reflector, the intensity of the beam may be reduced as much as 70 per cent, with a corresponding loss in distance or *pick-up* light.

To Test Lamp for Inaccuracy.—A practical method for determining whether or not the lamp filament is one sided is to rotate the lamp in the

reflector, when focusing, at the same time watching the patch of light. If the filament is located to one side of the axis of the reflector, the patch of light will rotate in a circle, depending upon the inaccuracy of the filament. Should the patch of light revolve in the same spot, however, the lamp may be considered suitable for headlight service. The pattern of light cast by a lamp with a one-sided filament is shown in Fig. 460.

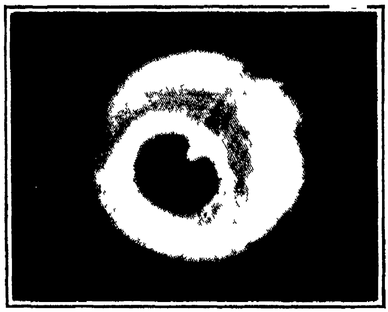


FIG 460.—Light produced by headlamp with filament inaccurately located

318. Glare and Its Causes.—It is difficult to form an exact definition of glare, as it varies with light conditions. It is generally accepted, however, that any light source produces glare if it appreciably reduces the distinctness of vision of any one looking toward it. Practically speaking, the blinding or dazzling effect of a light is not due so much to the brilliancy of the light as to the lack of illumination of the immediate vicinity through which the rays are projected. The headlamp, for example, which produces glare on a dark road at night would not cause the same effect on a well-lighted street, and in the day time with the sun shining it would hardly be noticed,—at least, it would not glare.

Naturally, the cause of glare at night is the directing of strong beams of light into the eyes of approaching drivers and pedestrians. Thus, if the strong light rays can be kept below the eye level—more on the road—and the illumination that must strike the eyes is reduced below the glaring value, the nuisance of glare will be largely eliminated. With this in mind, many tests have been conducted by the S. A. E. as well as the various states and manufacturers, in an attempt to determine the critical glare points, and also the maximum illumination in apparent candlepower which the human eye can stand without being blinded.

As a result two definite glare points have been established, as follows:

1. One-hundred feet ahead of the car and 60 in. high, in line with the car axis.

2. One-hundred feet ahead of the car and 60 in. high, but 7 ft. to the left of the car axis.

The results of the observations also showed that 2,400 apparent cp. should be the maximum amount of light at the center point, represented by No. 1, and 800 cp. as the maximum for No. 2. In determining these points it was found that, when two cars face each other on the highway, they are at considerable distance apart—at least 100 ft.—and the drivers can face a fairly bright light at the eye level of 60 in. without danger. Furthermore, when the average driver turns out, he does so at approximately 100 ft. from the approaching car and there is a distance of approximately 7 ft. between the two cars at that point.

The above glare points and maximum illumination values have been generally adopted and will be found embodied in the regulations of practically every state which has adopted headlight laws.

319. Minimum Light for Safe Driving.—The minimum amount of light for safe driving was determined in the same manner that the maximum glare values were determined, namely, by numerous observations with different light intensities. The values set in the regulations of some of the states, however, differ slightly, ranging between 1,200 and 4,800 cp. A safe driving light is considered a light which reaches a fair distance, usually 200 ft. or more on the level, yet gives sufficient spread or roadside illumination to show the ditches and objects approaching from the sides.

Therefore, two points have been chosen at which minimum values of light should be specified and adhered to in order to insure safe driving. One point is either 100 or 200 ft. directly ahead of the car, in line with the car axis, and at some point between 18 in. above the road and the level of the headlight bulbs. This location provides proper distance, or *pick-up*, light. The other point is 7 ft. to the right of the car axis, 100 ft. ahead of the vehicle, and at a point between the ground level and the level of the headlamp bulbs. This point provides for proper roadside illumination, particularly on the right.

320. The Foot-candle Meter.—The illumination at the different points specified in the headlight laws may be readily measured by an instrument called a *photometer* or *foot-candle meter*, shown in Fig. 461. To determine the illumination one merely holds the instrument at the different specified points and reads on the dial the *foot-candle* intensity.

The dial of the meter is in the form of a screen with a row of closely spaced translucent dots, resembling grease spots, running the entire length of the screen. A lamp within the case illuminates the under side of the screen to a much higher intensity at one end than at the other. If the illumination on the scale from the headlights being tested falls within the measuring limits of the meter, namely 0.5 to 0.25 ft.-candles, the spots will appear brighter at one end of the scale than at the other, and at the point where the spots are neither brighter nor darker than the white paper scale the illumination from the standard lamp within and from

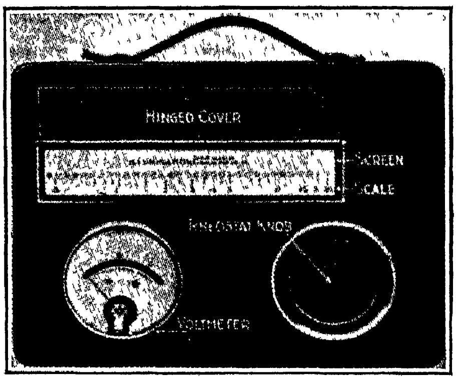


FIG 461.—The foot-candle meter.

the headlights from without is equal, and the mark at this point indicates the illumination in *foot-candles.*

The scale is accurately calibrated with the lamp within the meter burning at a certain definite voltage, which is supplied by small dry cells. A voltmeter and a rheostat on the front of the meter case permit the operator to adjust the lamp voltage to that at which the instrument was originally calibrated. Complete detail instructions covering the use of the foot-candle meter are usually included with each instrument.

321. Candlepower Ratings Called for by the Headlamp Laws of Various States.—The following are representative of the various state headlight law requirements:

NEW YORK

1. At 200 ft. ahead and 42 in. high, at least 1,200 cp.
2. At 100 ft. ahead and 60 in. high, not over 2,400 cp.

3. At 100 ft. ahead, 7 ft. to the left, and 60 in. high, not over 800 cp. Maximum size bulb is 24 cp.

CONNECTICUT

1. At 200 ft. ahead, between road level and lamp level, at least 4,800 cp.
2. At 100 ft. ahead and 60 in. high, not over 2,400 cp.
3. At 100 ft. ahead, 7 ft. to the left, and 60 in. high, not over 2,400 cp.
4. At 100 ft. ahead, 7 ft. to the right, and at lamp level or below, at least 1,200 cp. Maximum size bulb is 24 cp.

CALIFORNIA

1. At 200 ft. ahead on lamp level, not less than 1,200 cp.
2. At 100 ft. a head and 60 in. high, not over 2,400 cp.
3. At 100 ft. ahead, 7 ft. to the left, and 60 in. high, not over 800 cp.

PENNSYLVANIA

1. At 200 ft. ahead on lamp level, at least 1,200 cp.
2. At 100 ft. ahead and 60 in. high, not over 2,400 cp
3. At 100 ft. ahead, 7 ft. to the left, and 60 in. high, not over 800 cp.
4. At 100 ft. ahead, 7 ft. to the right, and between road level and lamp level, at least 800 cp.

WISCONSIN

1. At 100 ft. ahead, 60 in. high, not over 2,400 cp
2. At 100 ft. ahead, 60 in. high, and 7 ft. to the left, not over 800 cp.
3. At 100 ft. ahead and at a point between 18 in. above the road and the lamp level, at least 4,800 cp.
4. At 100 ft. ahead, 7 ft. to the right, and at a point between road level and lamp level, at least 1,200 cp. Maximum size bulb is 32 cp.

From the above it will be noted that the maximum or the minimum illumination in candlepower at the important points on the road is definitely specified and can be checked with the *foot-candle meter*. In most cases the maximum permissible bulb sizes are also specified. This not only tends to control glare but prevents over-loading the electrical system. As a rule, 21-cp. bulbs of proper design and adjustment will be found of sufficient capacity to produce the desired illumination, provided the reflectors are in good condition. In no case should the bulbs be larger than 32 cp.

322. Methods of Adjusting and Aligning Headlights.—The first step in adjusting the headlights to give proper road illumination is to locate the car in a level position, so that the light from the two headlamps will be thrown upon a wall or vertical screen approximately 25 ft. ahead of and at right angles to the car axis. Although most headlight regulations specify the maximum and the minimum illumination at the different points 100

ft. ahead of the car, the adjusting of the lamps themselves can best be made at one-fourth this distance, or 25 ft. When making the adjustments, the place should be well darkened, so that the light patches will be clearly defined. The procedure in adjusting and aligning the lamps is as follows:

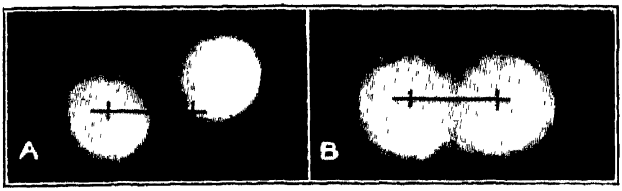


FIG 462.—(*A*) Light from a pair of head lamps out of alignment. (*B*) Light from a pair of head lamps at 25 ft. without anti-glare device and in proper adjustment.

1. Mark a horizontal line on the wall or screen at the height of the center of the lamps from the ground. On this line place two short, vertical marks directly ahead of, and at the same distance apart as, the centers of the two lamps.
2. Adjust both headlights to No. 1 focal adjustment, that is, the bulb position should be such as to give the smallest patch of light. If one circle

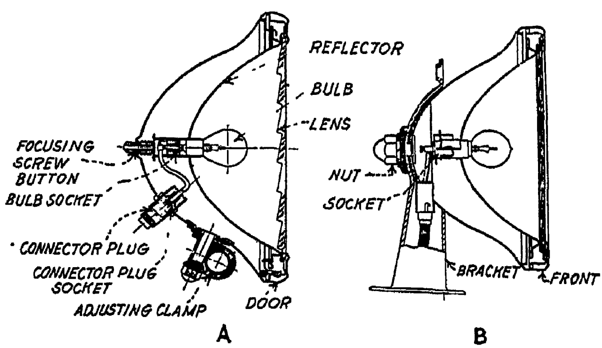


FIG. 463.—Sectional views of typical adjustable type head lamps (*A*) With adjustable clamp and external bulb adjustament. (*B*) With S. A. E. bracket mounting and internal bulb adjustment.

of light is too high, too low, or not on the mark, as shown in Fig. 462*A*, the headlight must be moved until the center of each light is at the mark, as shown in Fig. 462*B*. Some headlight brackets are made adjustable, as in Fig. 463, so that the proper alignment can be made readily by loosening the binding nut. In many cases, however, the bracket must be bent into the proper position by a wrench, as in Fig. 464. When the lamps are supported on the fenders, as in Fig. 465, they can usually be adjusted by loosening the

two bolts supporting the headlight and using shims of suitable shape and thickness beneath the bracket.

3. In case the lamps require a tilt of, say, 1 ft. in 100 ft. or 3 in. in 25 ft., in order to produce proper road illumination, the headlights must be tilted

FIG 464 —Method of bending lamp bracket to align Ford headlights

until the centers of the circles of light are 3 in below the line, as in Fig. 466. Should a greater tilt be required, say, 3 or 4 ft. in 100 ft, the light circles should be made to center on lines 9 and 12 in, respectively, below the normal lamp level.

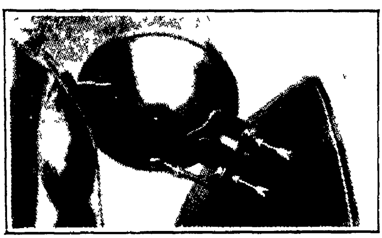


FIG 465 —Method of aligning headlamp when mounted on fender. Arrows indicate bolts which may be loosened for insertion of shims under bracket.

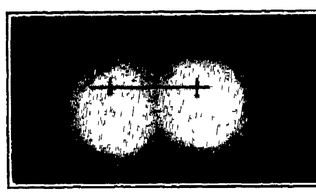


FIG. 466 —Light from pair of headlights at 25 ft properly adjusted for tilt of 1 ft in 100 ft

323. Home-made Devices for Preventing Glare.—Probably the best and most efficient home-made device to prevent glare is to cover one-half of the plain front glass with paper or paint, so that the light from one-half of the reflector—the half which would reflect the light rays upward—will be shut off. The preferred plan is to cover the upper half of the glass, as in Fig. 467, and

adjust the headlight to No. 2 focal adjustment. This shuts off the light from the upper half of the reflector, which would otherwise produce glare, while the lower half will reflect its light downward onto the road. If, however, the headlight cannot be adjusted to No. 2 focal adjustment, then No. 4 focal adjustment should be used and the lower half of the front glass covered or painted instead of the upper half. It should be remembered that with the No. 4 focal adjustment the light from the upper half of the reflector is reflected downward, while the light from the lower half is reflected upward, which accounts for the covering of the lower half.

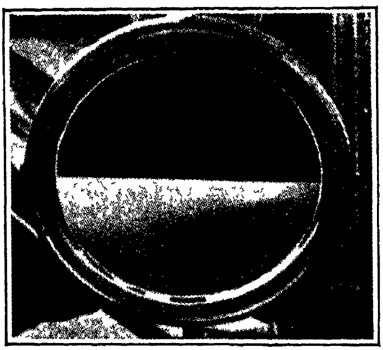


FIG. 467.—Home-made device for preventing glare.

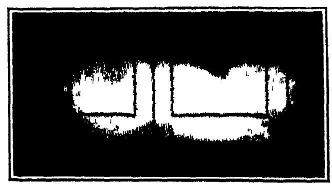


FIG. 468.—Pattern of light from properly adjusted headlamps equipped with home-made anti-glare device.

A properly adjusted home-made device should cut off the upper half of the beam, giving a pattern of light from both headlamps at a distance of 25 ft., as shown in Fig. 468. As will be noted, the light is cut off above the normal lamp level so that dangerous glare will be prevented.

324. Patented or Special Devices for Preventing Glare.—Home-made devices waste approximately one-half of the light from the headlights and are some trouble to make; therefore, numerous lenses and devices have been developed. Various schemes as follows have been used:

1. *By Dimming the Light.*—Since dimming of the headlights reduces road illumination in the same proportion as the glare, this method does not generally comply with the various headlight laws. For methods of dimming, see Art. 300. Section XVII.

2. *By Change in the Color of the Light.*—This method reduces the glare by decreasing the intensity of the light. Moreover, it reduces the road

illumination by the same amount and, therefore, has the same effect as dimming the light. This method does not generally comply with headlight regulations.

3. *By Scattering or Diffusing the Light Rays.*—This method reduces glare by breaking the beam of light and scattering the light through a wide solid angle. It is accomplished usually either by frosting the lamp bulb or by using a diffusing type lens, as stippled or frosted glass. This method may reduce glare, but the road illumination will also be reduced to values far below the limits specified for safe driving. No diffusing type of lens or device will generally comply with modern headlight regulations.

4. *By Deflecting the Upward Light Downward.*—This method reduces glare, and at the same time increases road illumination. It is usually accomplished by using prisms in the glass front to redirect, or bend downward onto the road, the light that would normally go upward from the reflector. This method is used in a majority of the so-called *deflecting-type lenses*, many of which comply with the headlight regulations, provided the lamps are in proper adjustment.

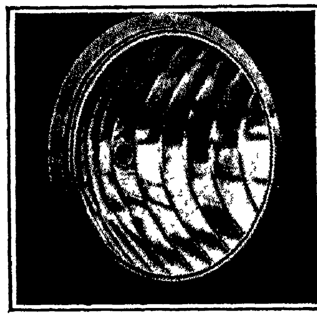


FIG. 469.—The Flatlite corrugated reflector used with plain front glass.

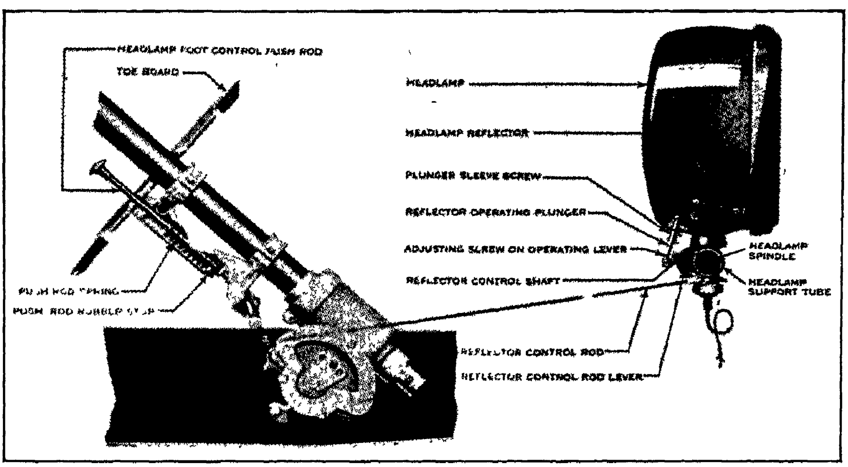


FIG. 470.—Tilting type of headlamp and reflector control mechanism as used on La Fayette car. Dotted lines show reflector in raised position.

5. *By Specially Constructed Reflectors.*—This method reduces glare and at the same time provides proper road illumination by directing the reflected light rays straight ahead and downward onto the road. An example of this type of reflector, known as the *Flatlite*, is shown in Fig. 469, which is standard

equipment on several prominent makes of cars, including the Chevrolet, the Oldsmobile, the Chandler, the Paige, and the Cleveland. The reflector is corrugated, the highly polished silvered surface being in the form of parallel fluted stripes running vertically and so designed as to spread the light outward and downward. It is used with a clear-glass front, and, if in proper adjustment, will comply with practically all headlight laws.

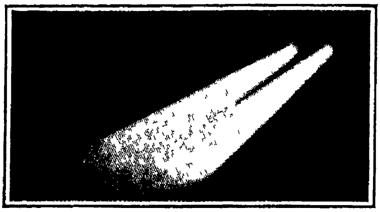


FIG. 471 —Light beams from head-lamps with tilting type reflectors. The dotted lines indicate the path of light with reflectors in raised position.

6. *By Tilting Reflectors.*—In Fig. 430 was shown a cross-sectional view of the tilting-reflector type of headlight as used on the Cadillac Eight, while Fig 470 shows the arrangement on the Lafayette car. The reflectors in the head-lamps are pivoted so that they may be tilted, being controlled by a lever or push rod on the steering column. When the road is clear and illumination of the distant road is desired, the reflectors are adjusted to direct the light

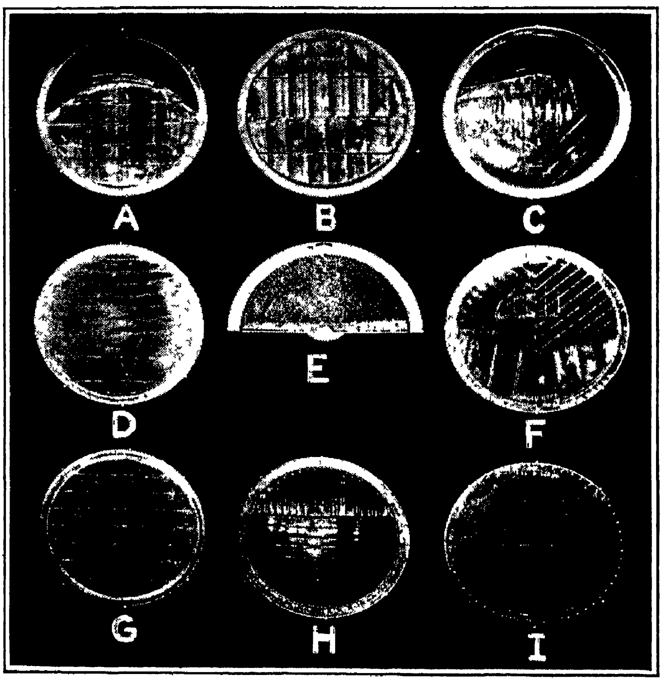


FIG. 472.—Typical anti-glare lenses.

straight ahead as indicated by the dotted lines, Fig. 471. When a vehicle traveling in the opposite direction approaches, the reflectors are tilted down by simply operating the lever or rod on the steering column, thus deflecting

the rays below the level of vision of the occupants of the approaching car and increasing the illumination directly in front of the car where it is most needed. These headlights will comply with the various headlight laws, provided the lamps are properly adjusted with the reflectors in the raised position.

325. Typical Patented Anti-glare Lenses and Devices.—Figure 472 shows a number of the patented anti-glare lenses on the market. Most of these devices operate on the principle of deflecting the light rays below the line of vision by prisms constructed in the glass, and will work satisfactorily only when the headlamp is properly adjusted. A partial list of the lenses approved by the state of Connecticut is given on p. 428. The same list will generally apply in other states, since the laws are quite similar. This list also gives the maximum permissible bulb sizes, the required focal adjustment, and the lamp tilt, if any.

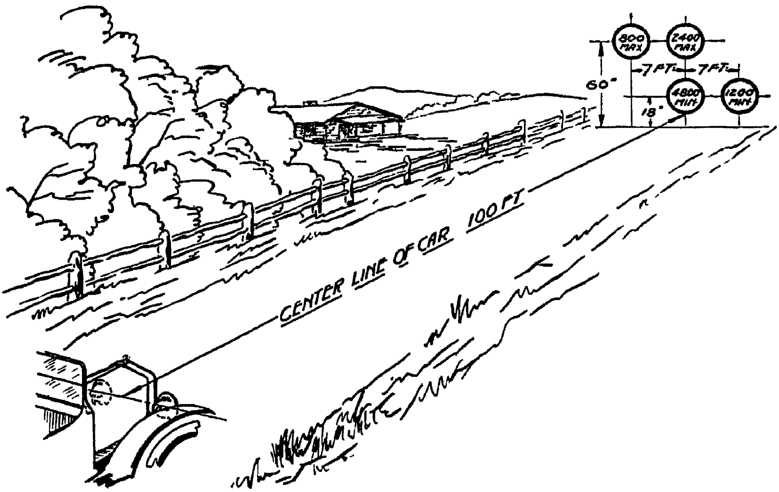


FIG 473 —Illumination requirements of headlights to comply with state laws

326. Methods of Checking Headlamp Illumination.—The most reliable method of checking headlamp illumination, in order to determine the actual intensity of light in candlepower at specified points 100 ft. ahead of the car, as shown in Fig. 473, is with the foot-candle meter. This method, however, requires the use of a reliable foot-candle meter and a thorough understanding of its use; consequently, it cannot be made by the average car owner—and in many cases not even by the average

PARTIAL LIST OF APPROVED ELECTRIC HEADLIGHT DEVICES (STATE OF CONNECTICUT)

Devices	Manufactured by	Maximum permissible candlepower of bulb		Focal adjustment	Tilt per 100 ft from horizontal beam, feet	Tilt per 25 ft from horizontal beam, inches
		Vacuum or "B" type	Gas-filled or "C" type			
Conaphore Clear	Corning Glass Works	24	21	No 1	1	3
Conaphore Noviol	Corning Glass Works	24	24	No. 1	1	3
Liberty	Macbeth-Evans Glass Co.	24	24	No. 1	No tilt	No tilt
Macbeth	Macbeth-Evans Glass Co.	24	24	No 1	No tilt	No tilt
Onlee	Spencer Wire Co.	23	24	No 1	3	9
Violet Ray	L E. Smith Glass Co.	21	22	No 1	No tilt	No tilt
Holophane	Holophane Glass Co.	15	21	No. 1	1	3
Full-Ray Deflector	Bradsto Appliances, Inc.	23	24	No 2	No tilt	No tilt
Osgood	Osgood Lens Co.	15	21	No 2	1	3
Roadlight Dimmer	W. T. Smith Mfg. Co.	16	24	No 2	1	3
National	L. E. Smith Glass Co , Mt. Pleasant, Pa.	19	24	No 1	No tilt	No tilt
Bausch & Lomb	Bausch & Lomb Optical Co , Rochester, N. Y.	18	22	No 1	1	3
McKee	McKee Glass Co., Jeannette, Pa.	15	21	No 2	No tilt	No tilt
Legalite Mark III	Legalite Corp.	24	24	No 1	No tilt	No tilt
Saftee	Super Glass Co.	24	24	No 2	No tilt	No tilt
Legalite Old Type	Legalite Corp.	19	24	No 1	2	6
Paterson	Warner-Patterson Co.	21	24	No 1	No tilt	No tilt
Nevablind	A. Shickerling	16	21	No 4	No tilt	No tilt
Fractor	Fracto Specialty Co.	21	21	No. 4	No tilt	No tilt
Raydex	Raydex Mfg. Co	15	21	No 2	16 in.	4
Shaler Roadlighter	C. A. Schaler Co.	23	24	No 2	No tilt	No tilt
Benzer	Benzer Corporation	24	24	No 1	No tilt	No tilt
Home-made device (upper half painted)	....	24	24	No. 2	No tilt	No tilt

The headlights on Ford cars taking current from the flywheel generator must be tilted 1 ft in 100 ft. in addition to that specified above.

auto mechanic or electrician. He should, however, be able to check the headlights for glare.

Checking Headlights for Glare.—A quick method of checking headlamp illumination for glare is as follows:

1. Stop the car within 25 ft. of some vertical surface and draw on that surface a horizontal line at same height of the center of the headlamps. If the two semi-circles of light are confined to the area below this line, as in Fig. 468, the lamps are adjusted properly and will not glare.

2. If a vertical surface is not available, place the hand on the center of the headlamp and then hold the hand at this level against the body, walking backward about 25 ft. from the front of the car, keeping within the beam of light. If the intense rays of light fall below the hand at a distance of 25 ft. from the car, the adjustment may be considered satisfactory. This test should be made for each headlamp. Light distribution from headlamps equipped with typical approved patented lenses of the deflecting type, with lamps in proper adjustment, is shown in Fig. 474.

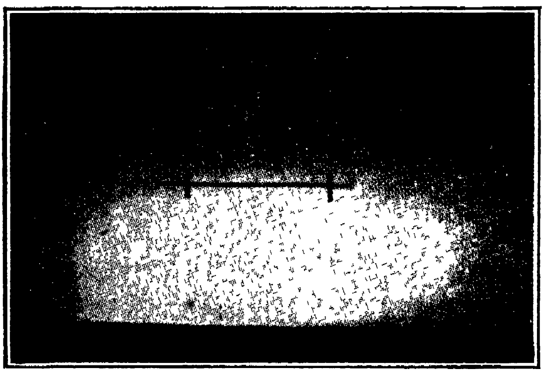


FIG. 474—Distribution of light from headlamps equipped with approved patented lenses with lamps in proper adjustment.

327. Cleaning Reflectors.—Reflectors are plated with pure silver and are highly polished and so may be scratched in cleaning unless care is exercised, even if they are cleaned with soft material. If they have become dull from long service, or from exposure, they may be polished with a clean chamois and rouge or crocus, such as is used by jewelers for cleaning watches. Lampblack moistened with water or gasoline may also be used. The chamois should be soft and free from dust, and should not be used for any other purpose. The chamois and rouge, dampened with alcohol, should be used first to remove any spots or heavy tarnish. The reflector should then be wiped off, using a second piece of chamois, with dry rouge. This will give a high finish. The polishing

should be done in an in-and-out motion, to avoid leaving marks on the reflector. The fingers should not come in contact with the reflecting surface.

328. Lighting Troubles and Their Causes.—The most common of the lighting troubles may be determined by a study of the following cases:

1. *Lamps in One Circuit Do Not Burn.*—This may be caused by a lamp being burned out, a blown fuse, or a broken or loose connection in the wiring. It may also be due to rust or paint between the reflector and the lamp housing or between the lamp bracket and the car frame, in the grounded-type system.

2. *None of the Lamps Will Burn with Engine Stopped.*—This may be due to (*a*) all lamps being burned out; (*b*) main lighting fuse being blown; (*c*) corroded or loose battery terminals; (*d*) battery ground wire being disconnected or making poor contact; (*e*) main lighting switch wire being broken or disconnected; (*f*) circuit-breaker contacts (Delco type) not closing properly; (*g*) ammeter open-circuited; (*h*) battery being completely discharged; or (*i*) wrong type of lamps.

3. *Lamps Go Out for an Instant Only.*—If the lamps in one circuit act this way, there is probably a loose connection on the circuit so affected. If all the lamps go out for an instant, there is probably a loose connection in the lighting circuit from the battery to the lighting switch or fuse block, or the switch does not make good contact. This condition may also be caused by a temporary or "flying" ground on the main lighting circuit between the battery and the lighting switch.

4. *Lamps Become Dim When Engine Stops.*—This indicates either a discharged battery or a poor battery connection. If the battery is discharged, it should be recharged at once from an outside source. If this cannot be done, the engine should be cranked by hand and the lights used sparingly for several days, or until the battery charge picks up again.

5. *One Lamp Burns Dim and the Other Bright.*—This may be due to (*a*) a lamp bulb of wrong voltage or candlepower; (*b*) headlight connecting plug being upside down; (*c*) lamp bulb being installed upside down in the double-filament type, such as the Ford; (*d*) wrong wiring of lighting switch; (*e*) lamp bulb out of focus; and (*f*) tarnished reflectors.

6 *Headlights Too Dim or Too Bright with Lighting Switch on Dim Position.* This condition is usually caused by using dimmer resistance of the wrong capacity. The size of headlight bulbs should not be changed without changing the dimmer resistance accordingly.

7. *One Lamp in a Series Continues to Burn Out.*—This is usually caused by one lamp being of a different capacity than the other one in series with it. Both lamps should be of the same voltage and candlepower, otherwise the smaller lamp will burn out first.

8. *All Lamps Burn Out Repeatedly.*—This is usually due to improper regulation of the generator caused by: corroded battery terminals, the failure of the cutout to close, or a loose or broken connection in the battery-charging circuit.

SECTION XIX

ELEMENTS OF STARTING AND GENERATING EQUIPMENT

329. Types of Starting Systems.—Devices for starting automobile engines may be classified under four general heads, namely, mechanical, air, acetylene, and electric.

Mechanical Starters.—Mechanical starters include the various types of hand-cranking devices and springs. This method of cranking was used on many early automobile engines, but because of its many disadvantages it gave way to more modern methods. The only advantage of this method of cranking is that the driver can in many cases crank the engine over a few turns without leaving his seat. If the engine does not start, however, it becomes necessary for him to get out and either crank the engine by hand or wind up the spring in the mechanical device, a rather tiresome operation. When the engine starts, an automatic device is provided by which the spring of the mechanical starter is wound up preparatory for the next cranking.

Air Starters.—Some of the first automobiles were equipped with starters using compressed air, the air being maintained in a storage tank at a pressure of about 150 lb. By this method the engine was cranked either by admitting air into the combustion chamber or by a compressed-air motor attached to the crankshaft. The chief disadvantage in using air for starting is the difficulty in preventing air leaks.

Acetylene Starters.—Another method of starting the engine on the older cars was by injecting acetylene gas into the various cylinders in their order of firing, the acetylene being taken from the acetylene lighting supply used on the early makes of cars. As this gas is explosive, it ignited readily under almost any condition. These engines were equipped with valves and tubes from the acetylene lighting system, so that the driver could inject a small quantity of acetylene gas into the engine cylinder. The engine would usually start itself upon the production of a spark within the cylinder.

Electric Starters.—The electric starter was first adopted in 1912. It is in the form of a low-voltage direct-current motor, the current for operating it being supplied by a storage battery. The same battery also furnishes the current for the lighting system, and, in most cases, for the ignition as well. The electric starter is now used universally on all makes of passenger cars and a large percentage of the trucks.

330. Component Parts of Typical Electrical Starting System.—A typical electric starting system consists essentially of the following component parts;

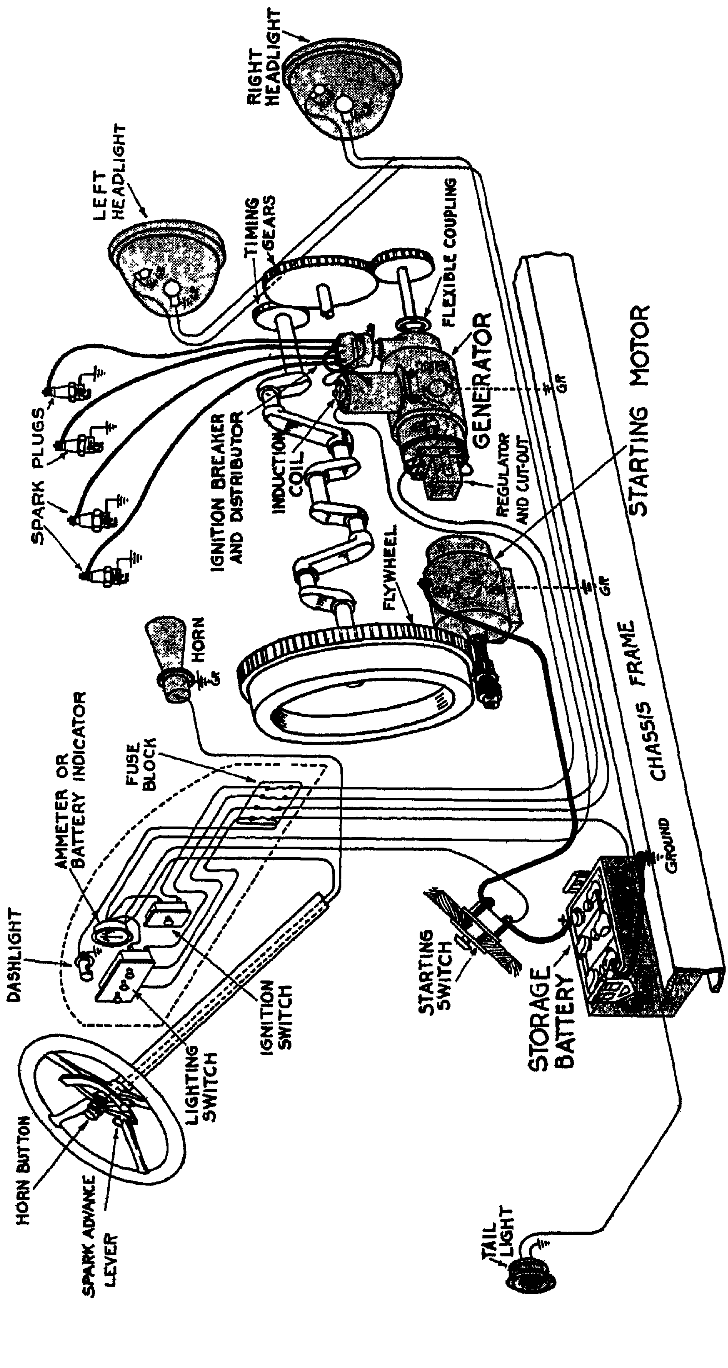


FIG. 475.—Installation and wiring of typical two-unit electric starting, lighting, and ignition system

1. A direct-current starting motor which will operate on current from the storage battery for cranking the engine.

2. A storage battery for supplying current when the generator is not running or is not running fast enough to generate the required amount of current.

3. A direct-current generator for keeping the battery charged.

Electric starting and generating systems may be divided into two general classes according to the number of machines required to perform the generating and the cranking operations, namely, the *single-unit* and the *two-unit* systems. In the single-unit system the generator and the starting motor are combined into one machine known as a "motor-generator" or "starter-generator." In this system the machine operates as a motor, which uses current from the battery when the engine is being cranked. When it is driven by the engine, however, it converts itself automatically into a generator to charge the battery.

In the two-unit or "double-unit" system the generator and the starting motor are separate and comprise two independent machines. In this type of system the generator is driven continuously by the engine, while the starting motor is normally disconnected from the engine through the driving mechanism and operates only when the engine is to be cranked and the starting switch is closed. A diagram showing the installation of a typical two-unit system is shown in Fig. 475, which illustrates the single-wire grounded-type system. The current for ignition, horn, lights, starting motor, etc. returns to the battery through the ground or frame of the car, instead of by a separate wire. This method of car wiring, in preference to the two-wire method, is used by practically all automobile manufacturers, since the use of the frame as one conductor greatly simplifies the wiring of the car and, in many cases, the construction of the starting and the lighting apparatus as well.

The voltage at which the system operates is usually 6 volts, although in some installations 12 volts are used. In many of the first systems a double voltage or *split battery* was used, such as the 6 volt-12 volt, 12 volt-24 volt, and the 6 volt-24 volt types. The cells of the battery were divided into two groups connected in parallel, giving the lower voltage when being charged and for operating the lights, but connected in series to give the higher voltage for operating the starting motor when the starting switch is closed. Owing to the many disadvantages of the double-voltage system, it has been prac-

tically discarded in favor of either the single 6-volt or the 12-volt system. The voltage of a system can readily be determined by noting the storage battery, since a 6-volt system uses a three-cell battery and a 12-volt system a six-cell battery.

331. Hydraulic Analogy of Typical Electric Starting and Generating System.—The operation of the different parts of an electric starting and generating system may be compared to the operation of a small water system such as is commonly used in small towns or in isolated private residences. The hydraulic analogy is shown in Fig. 476. Such a water system usually com-

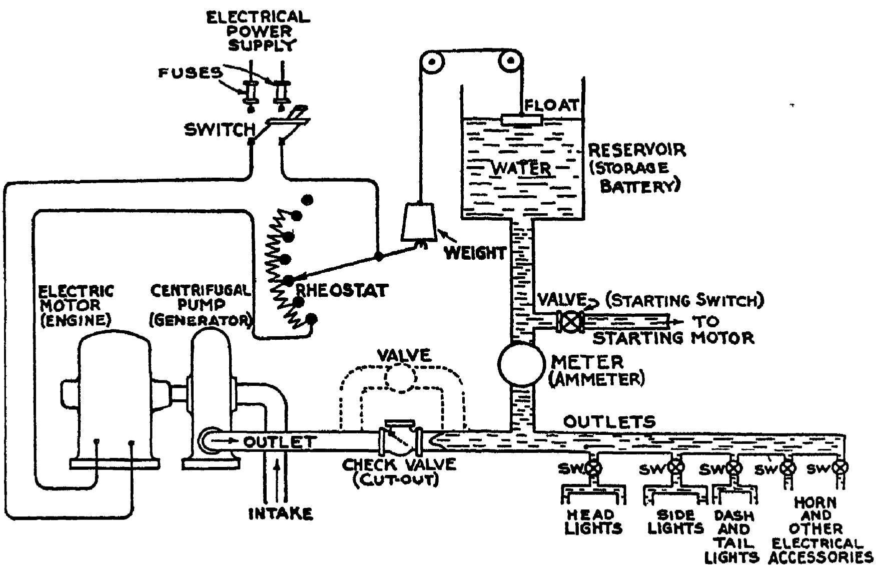


FIG. 476.—Hydraulic analogy of electric starting and lighting system.

prises a motor-driven pump, connected by a main line to the various outlets, and a tank or reservoir placed at a height which will give the desired head or pressure.

The pressure tank or reservoir is provided with a regulator, usually of the float type, adapted to indicate the amount of water in the reservoir and to shut off or reduce automatically the power of the pump when the water has reached a certain predetermined level. This may be accomplished by connecting the float regulator to the switch or rheostat (adjustable resistance) in the main circuit of the motor which drives the pump. The speed

of the motor and the output of the pump will be regulated in accordance with the quantity of water being drawn from the system. If the quantity of water drawn from the system exceeds that supplied by the pump at a given speed, the reservoir will supply the difference. When the level of the water falls to a certain point, the motor will run faster, thus increasing its output and making up for the greater demand.

It will be noted that a check valve is placed in the main line between the pump and the reservoir. The purpose of this valve is to prevent the backward flow of water into the pump in case the pressure due to the water in the reservoir exceeds that of the pump, or in case the pump is stopped.

In general, the reservoir in the water system corresponds with the storage battery in the starting system. The pump corresponds with the generator which is driven by the engine, the float-regulating device with the regulating relay for controlling the generator output, and the check valve with the cutout of the electric system. The meter registers the amount of water either pumped into or discharged from the reservoir and corresponds to the ammeter, Fig. 475, connected in the generator-charging circuit.

The operation of the system is comparatively simple. When the current output of the generator exceeds the amount required by the lights, ignition, etc., the excess current will flow through the battery in the charging direction so that the ammeter will show "Charge." For example, if the lamps require 8 amp. and the generator output is 12 amp., the ammeter will show a 4-amp. charge. On the other hand, if the generator is only supplying 8 amp., the same as required by the lights, the battery will neither charge nor discharge and the ammeter will read zero. But if the generator produces less current than is required by the lights, say only 5 amp., the battery will supply the amount which the generator is deficient in and the ammeter will show a discharge of 3 amp.

It will be noticed from the diagram that the current for the starting motor does not pass through the ammeter, since the motor requires a current large enough to burn out the ammeter. Provided the lamps are of the proper size, the generator output should be so regulated that at normal driving speeds, with all

the lights and ignition turned on, there will be at least 3 to 5 amp. charging the battery. This is necessary to compensate for the current used periodically by the starting motor and the horn, and in order to insure keeping the battery fully charged.

By making a few minor changes, such as forming a by-pass around the check valve, the analogy of Fig. 476 will apply equally well to the single-unit system, in which case the pump will act as a water motor when the valve in the by-pass is opened and the water allowed to discharge through it from the reservoir. The pump then corresponds in action to the motor-generator, and the valve in the by-pass to the starting switch. Thus, this switch, by short-circuiting the cutout, permits the battery to discharge through the motor.

With the connections as shown, the ammeter must carry the starting current. But since the starting current is usually more than the ammeter is designed to carry without injury, the ammeter must be either eliminated or replaced by a *battery indicator* which will carry a large current. The battery indicator does not register the number of amperes flowing, but merely indicates which way the current is flowing through the battery. It is usually referred to as the C. O. D. indicator, because it registers three readings, "Charge," "Off," and "Discharge." See Art. 425, Sec. XXVIII.

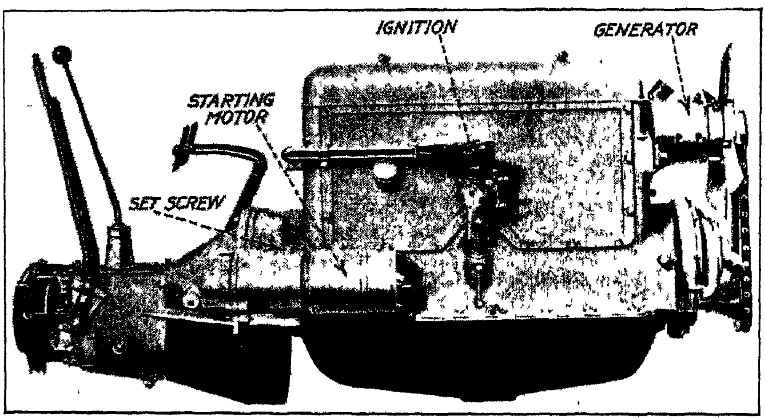


FIG. 477.—Installation of Delco starting, lighting and ignition equipment on Nash Six.

332. Methods of Mounting and Driving Generators.—The method of mounting and driving the generator depends to a large extent upon the type of engine on which it is equipped. Therefore, the problem varies with the different makes of cars. In the

two-unit system, in which the generator and the starting motor are separate, the generator is usually mounted on the side of the

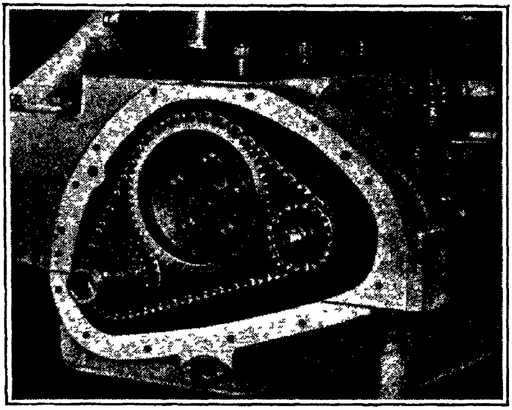


FIG. 478.—Chain driven generator on Willys Knight engine.

engine and driven from the camshaft gear at one to one and one-half times crankshaft speed. The method of drive may be by belt,

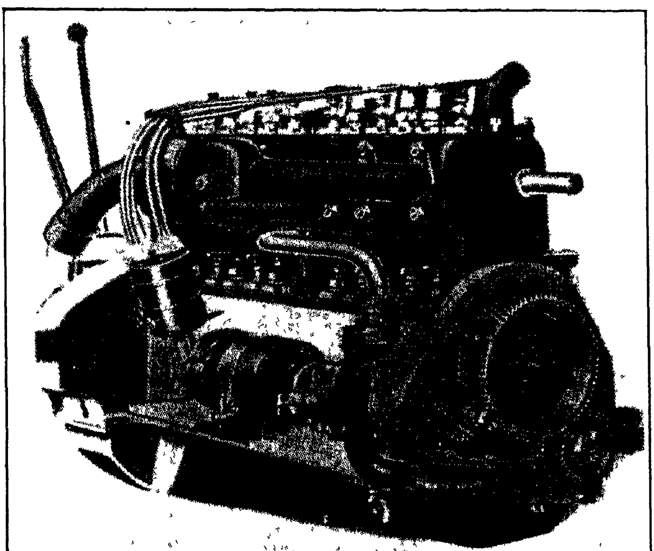


FIG. 479.—Generator driven by pinion from timing gear on Case Continental Six engine.

silent chain, or gears, the gear drive being the most popular method. Typical generator mountings showing the belt, the

silent chain, and the gear methods of drive are shown in Figs. 477, 478 and 479.

Belt Drive.—When the generator is driven by a belt, as in Fig 477, some method must be provided for adjusting the belt tension from time to time. This is usually done by raising or lowering the generator. The tension should be such that the generator is driven at proper speed without undue slippage of the belt. The belt tension should not be so tight, however, that it will injure the bearings of the generator.

Silent-chain Drive.—The silent-chain method of drive, Fig. 478, provides a positive method of driving the generator, but requires adjustment from time to time in order to compensate for the increasing length of the chain, due to wear. This method of drive is more commonly used in driving a motor-generator, for example, the North East starter-generator on the Dodge

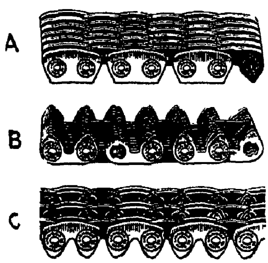


FIG. 480.—Types of link-belt silent chains.

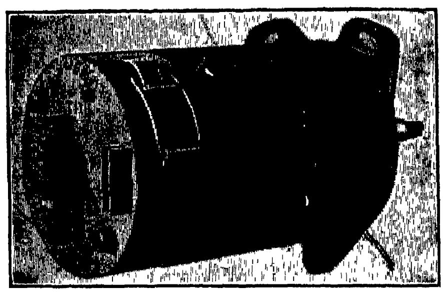


FIG. 481.—Westinghouse generator with flange mounting.

car and the Dyneto motor-generator as was used on the Franklin and the Holmes. Types of link-belt silent chains are shown in Fig. 480, showing the "side-flange" type, *B* the "center-flange" type, and *C* the "back" type, respectively.

Gear Drive.—The gear method of drive is by far the most popular. The generator may be driven through a flexible coupling and a shaft driven by the timing gear, as in Fig. 479, or it may be bolted directly to the timing gear housing by flanges cast on the generator frame, as in Fig. 481. In this case the pinion on the generator armature shaft meshes directly with one of the timing gears, doing away with the drive shaft and the coupling. This method of installation gives a very rigid mounting, insures perfect alignment of the bearings, and makes the generator accessible in case it is to be removed for repair.

333. Generator-drive Couplings.—When the generator is mounted on the side of the engine and is driven from an extension of the water pump or magneto shaft, as in Figs. 482 and 483, a flexible coupling must be used which will permit proper driving

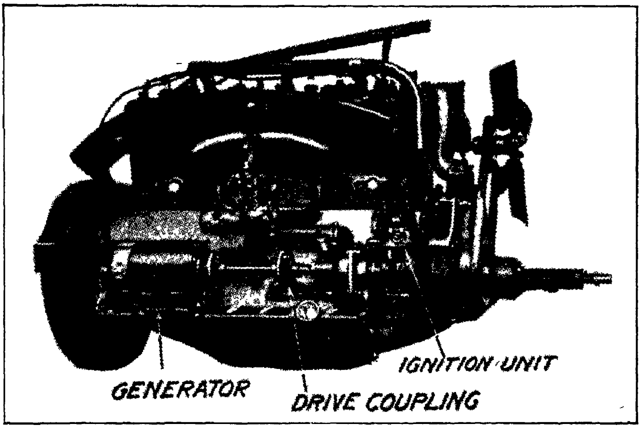


FIG. 482.—Right side of Jordan engine showing Delco generator installation.

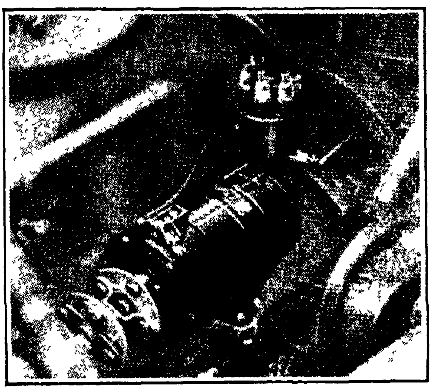


FIG. 483.—Installation of North East generator on Reo six cylinder engine, series B, showing driving coupling.

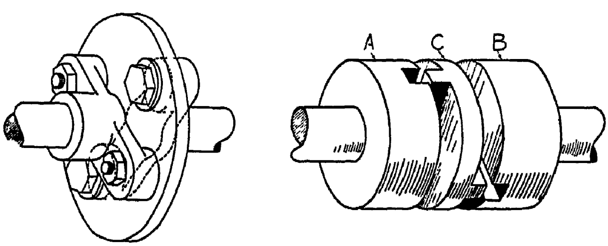


FIG. 484.—Generator drive couplings. (*A*) Flexible disc coupling. (*B*) Oldham coupling.

of the generator armature, even though the two shafts may not be in true alignment. Typical couplings are shown in Fig. 484. *A* shows the flexible-disc type, the disc being usually of leather or of rubberized fabric, while *B* shows the Oldam coupling, in which the two ends *A* and *B* connect through the center piece *C* which has two splines, one on either side at right angles which fit into square-type grooves on the end pieces. When the joint is assembled, the piece *C* is held between the two end pieces and cannot escape. The power is readily transmitted through the three parts, the construction of which permits some angularity between the two shafts. The same type couplings are also used for driving magnetos.

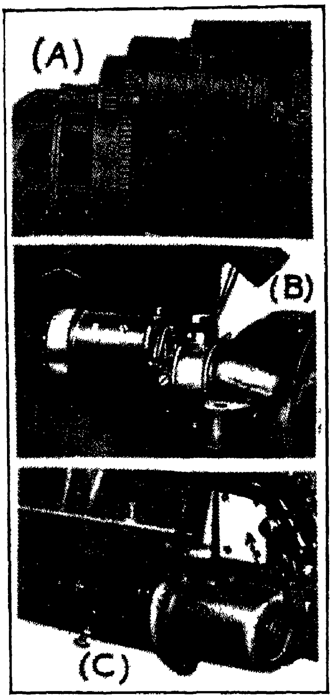


FIG. 485.—Typical starting motor installations. (*A*) Marmon. (*B*) Jordon. (*C*) Dort.

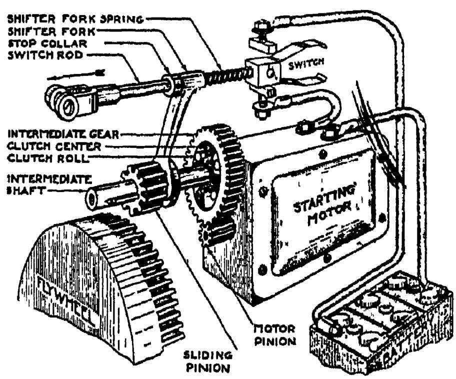


FIG 486 —Sliding pinion type of motor drive. (*Early Gray & Davis*)

334. Starting-motor Drives.—The starting motor is usually mounted on the side of the engine by a bracket or flange connection to the cylinder casting. Typical installations are shown in Figs. 477 and 485. In Figs. 477 and 485*B* the rear end of the starting motor casting has a machined neck which fits into a cylindrical hole in the flywheel housing, the motor being held in place by a single set screw.

The starting motor may drive the engine by a silent chain and over-running clutch, or by a pinion attached to the motor armature shaft which is brought into mesh with teeth cut on the rim of the

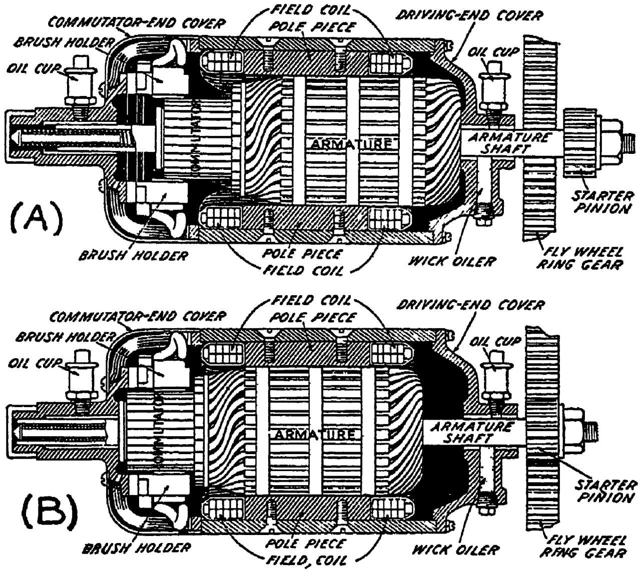


FIG. 487.—Sectional views of Rushmore starting motor with magnetically shifted armature for engaging pinion with flywheel. (*A*) Showing pinion out of engagement (*B*) Pinion engaged.

flywheel. The latter method has many advantages and is used almost universally on two-unit systems, while the chain drive is used more extensively on single-unit systems.

FIG. 488.—Westinghouse starting motor with automatic electromagnetic pinion shift.

There are three principal methods of connecting the motor to the flywheel: (1) The *sliding pinion type*, Fig. 486, in which a pinion is shifted by the operator as the starting switch is closed, the operation of which depends more or less upon the skill of the

operator; (2) the *magnetic* type, in which either the entire armature is automatically shifted by magnetism pulling the pinion into mesh, as in Fig. 487, or the pinion only is shifted, as in Figs. 488 and 489; and (3) the *Bendix drive*, Fig. 490, which is automatic and which requires little attention and skill on the part of the operator. The last method is used on practically all cars equipped with the two-unit system.

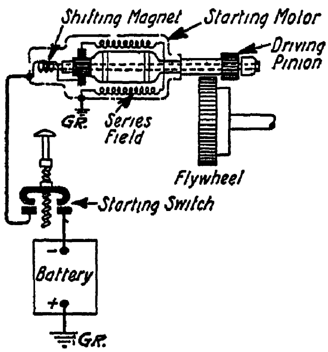


FIG. 489.—Diagram of Westinghouse starting motor with automatic electromagnetic pinion shift.

The gear reduction obtained through the flywheel-type starter with single reduction is usually about 11 or 12 to 1; that is, the speed of the motor armature is 11 to 12 times that of the flywheel. With the single reduction, the pinion gear on the armature shaft meshes directly with the gear teeth on the flywheel. In some cases, however, a double reduction is used, in which the gear ratio may be as high as 25 or even 40 to 1.

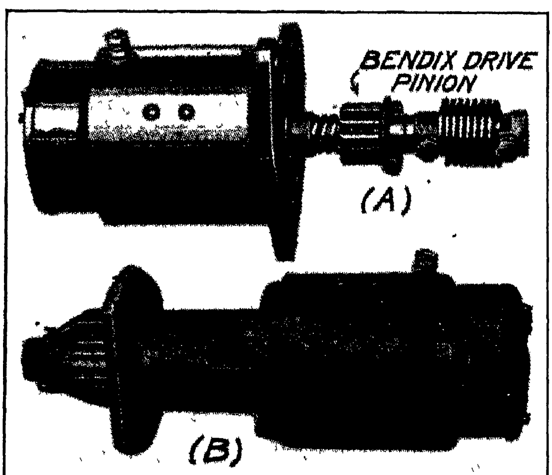


FIG. 490.—Starting motors with Bendix drives. (*A*) Inboard type. (*B*) Outboard type.

With the double reduction, as shown in Fig. 491, the pinion gear *A* on the armature shaft does not mesh directly with the teeth on the flywheel, but with an intermediate gear *B*, which, in turn,

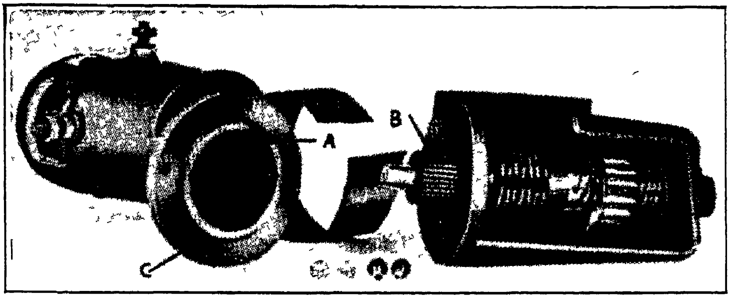


FIG. 491 —Wagner starting motor with double reduction drive.

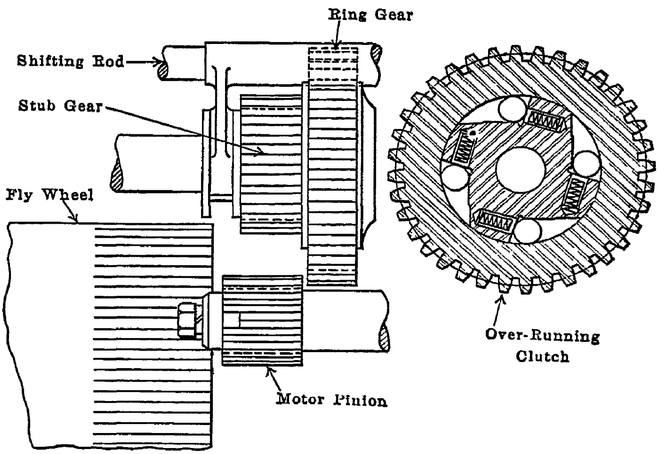


FIG. 492.—Starting gears and over-running clutch on Delco motor-generator.

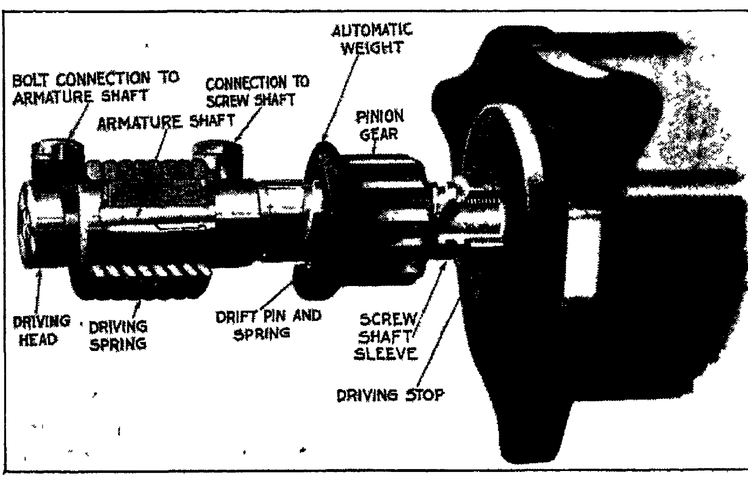


FIG. 493.—Construction of Eclipse-Bendix drive. Inboard type.

drives the flywheel driving pinion. The double-reduction drive permits the use of a small starting motor running at high speed, but it is more complicated than the drive mechanism of the single-reduction type.

Owing to the high-gear ratio between a starting motor of the flywheel type and the engine, some provision must be made to prevent the engine from driving the motor at excessively high speeds when the engine starts under its own power. In starters having the sliding-pinion type of drive, as shown in Fig. 486, this is taken care of by an over-running clutch incorporated in the intermediate gear, which slips when the flywheel tends to drive the starting motor. Figures 492 and 494 show the construc-

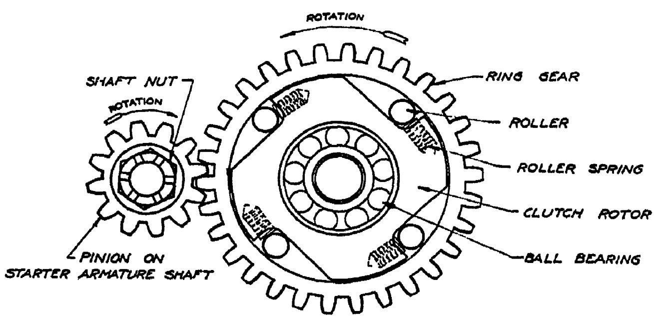


FIG. 494 —Construction of over-running clutch.

tion of a typical over-running clutch. In starters with either the magnetic or the Bendix type of drive, the driving pinion is automatically thrown out of mesh with the flywheel gear as the engine speeds up under its own power.

335. The Bendix Drive.—The automatic screw-pinion shift mechanism, known as the Bendix drive, Fig. 490, is built in two distinct styles, the *inboard type*, Fig. 490*A*, in which the pinion shifts toward the motor to engage with the flywheel, and the *outboard type*, Fig. 490*B*, in which the pinion shifts away from the motor. The outboard type requires a third bearing to support the outer end of the shaft.

The construction of the inboard type is shown in Fig. 493. A sleeve having screw threads (usually a triple thread), with stops at each end to limit the lengthwise travel of the pinion, is mounted on the extended armature shaft. The pinion, having corre-

sponding internal threads, is mounted on this sleeve. The pinion is weighted on one side. The sleeve is connected to the motor armature shaft through a coil spring attached to a collar pinned to the armature shaft. The same construction is used in the outboard type.

The operation of the Bendix drive is as follows. The pinion is normally out of mesh and entirely away from the flywheel gear. When the starting switch is closed and the full-battery voltage is impressed on the motor, the armature immediately starts to rotate at high speed. The pinion gear, being weighted on one side and having internal screw threads, will not rotate immediately with the shaft, but, because of its inertia, will run forward on the revolving screw sleeve until it meets or meshes with the flywheel gear. If the teeth of the pinion and the flywheel meet instead of meshing, the spring will allow the pinion to revolve until it meshes with the flywheel. When the pinion is fully meshed with the flywheel teeth, the spring compresses. The pinion is then driven by the motor through the spring and turns the engine over. The spring acts as a cushion while the engine is being cranked against compression. It also breaks the severity of the shock on the teeth when the gears mesh, and in case the engine should kick back due to early ignition. When the engine fires and runs on its own power, the flywheel drives the Bendix pinion at a higher speed than does the motor armature, causing the pinion to be turned in the opposite direction on the screw and to be demeshed from the flywheel automatically. This prevents the engine from driving the starting motor. The centrifugal effect of the weight on one side of the pinion, when it is automatically demeshed from the flywheel, holds the pinion to the sleeve in a demeshed position until the starting switch is opened and the motor armature comes to rest.

336. Characteristics of the Bendix Drive.—Among the chief advantages claimed for this type of motor drive are:

1. Simplicity of construction.
2. Mechanism automatic in operation, requiring no skill from the operator.
3. High-cranking speed, because the starting motor is permitted to attain full speed before the load is applied.
4. The engine is given a high "break away" cranking torque, thus requiring the minimum amount of cranking and minimizing the demand on the battery.
5. Better carburetion and easier starting in cold weather, due to higher cranking speeds.

337. The Over-running Clutch.—The purpose of the over-running clutch is to transmit motion and power in one direction.

It is used in starting motors which drive by a silent chain, and also in single-unit motor-generators which are driven as a generator at one speed, but crank the engine with the armature running at a different speed ratio. Examples of the over-running clutch vary somewhat with the method of installation and with the duty which it is to perform.

Over-running Clutches for Starting-motor Drives.—The principal parts of a typical over-running clutch for motor drives are shown in Fig. 494. The outer race of the clutch-ring gear is driven by the starting motor, the inner portion of the clutch rotor being connected to the pinion, which meshes with the teeth on the engine flywheel. When the engine operates on its own power and tends to drive the armature pinion faster than it normally rotates, the clutch will slip, preventing the driving of the armature. This is done

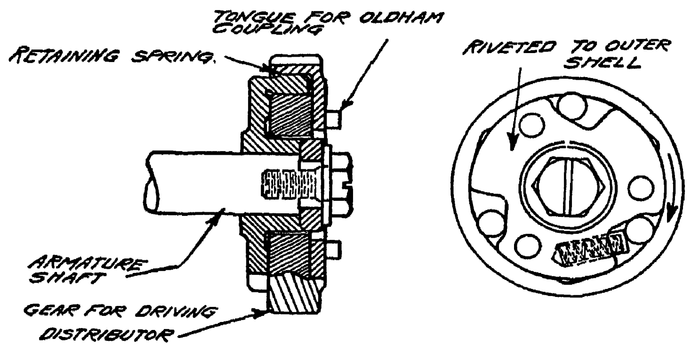


FIG. 495.—Delco generator over-running clutch—noisy type.

by the steel rollers. As will be noticed from Fig. 494, each roller is located in a wedge-shaped space between the outer surface of the center piece and the inner surface of the driving member. Each roller has a small plunger pressing against it under spring tension, which tends to keep it firmly compressed within the wedge angles at all times. As soon as the starting-motor shaft turns, the rollers are pinched between the wedge-shaped surfaces, causing both the inner and the outer members to rotate as a unit and the motor will crank the engine. As soon, however, as the engine tends to transmit power through the clutch in a reverse direction, the rollers are released from the wedge-shaped angle due to friction, permitting the over-running of the clutch.

Over-running Clutches for Generator Drives.—A typical generator-drive type of over-running clutch is shown in Fig. 495. This shows the *noisy* type used in many models of Delco generators where a cutout is not used in the battery and generator circuit. As will be noted, there are several depressions in the inner surface of the outer member into which the rollers may drop when the clutch is over-running.

In case the engine is stopped and the ignition switch—which also operates the charging circuit—is left on, the battery will discharge through the generator, the over-running clutch enabling it to rotate as a motor without driving the engine. As the armature rotates, the rollers passing over the depressions in the outer member cause a clicking sound, indicating that the switch is on and the armature is revolving. Also, when the generator is being driven through the clutch, the depressions prevent slipping of the rollers, thus providing a positive drive.

SECTION XX

THE GENERATOR AND THE REVERSE-CURRENT CUTOUT

338. The Direct-current Dynamo.—The principles of operation of the simple alternating- and direct-current generators were explained in Arts. 38 and 39 of Sec. II. In Art. 40 the fundamentals of the D.C. motor were also explained. Fundamentally, the dynamo is an electric machine used for the conversion of either electrical energy into mechanical energy, or mechanical energy into electrical energy. When it is used for converting electrical energy into mechanical energy, it is called a *motor*, and when it is used for converting mechanical energy into electrical energy it is called a *generator*. When a dynamo is used both as a generator and as a motor—for it may operate as either—it is usually termed a *motor-generator*, a *starter-generator*, or a *dynamotor*.

339. Construction of the Generator.—The component parts of a typical automobile generator are shown in Fig. 496. They consist essentially of an armature, a field frame, pole pieces, field coils, brush rigging, and brushes. The construction differs materially from the magneto, since the generator operates in conjunction with the storage battery and must generate direct current. It must also be designed to permit regulation of the generator output at high engine speeds to prevent over-loading of the generator and over-charging of the battery. This, of course, is unnecessary in the magneto used for ignition purposes. Instead of using permanent magnets for producing the magnetic field, the field is usually produced by electromagnets or "poles" magnetized by *field winding* or *field coils* through which direct current is made to flow.

The field frame may be either an iron or steel casting or it may be built up of soft-iron laminations. In some cases it may also be made up of a short piece of steel tubing, 4 to 6 in. in diameter,

in which poles of soft iron are held in place by machine screws. The frame may have two, four, or six poles, although the two-

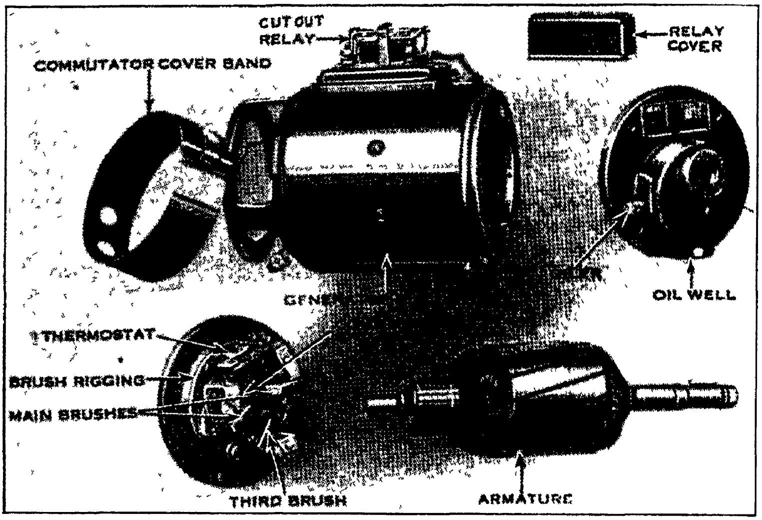


FIG. 496.—Component parts of a typical automobile generator. (*Remy.*)

and four-pole frames are the most common. Figure 497 shows several types of dynamo frames commonly used and the magnetic

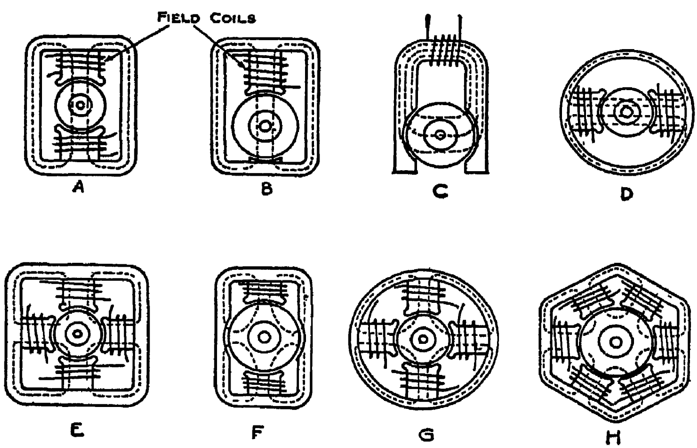


FIG. 497.—Types of dynamo field frames.

field circuits (dotted) in each. In some types of dynamo frames the field winding is wound on each pole, while in others there is but one field coil to two poles, in which case more winding is put

in a single field coil instead of distributing it in smaller coils on all the poles. In the two-pole-type frame, the magnetic field flows diametrically through the armature, while in the four- and six-pole types each magnetic circuit cuts through one-fourth and one-sixth

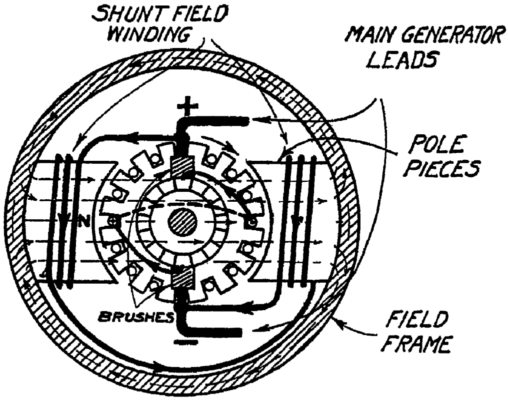


Fig. 498.—Circuits of simple shunt-wound generator.

of the armature core respectively. For this reason the armature must be constructed and wound in accordance with the number of field poles, since it is the cutting of the magnetic field by the winding on the armature in passing the pole pieces which permits the

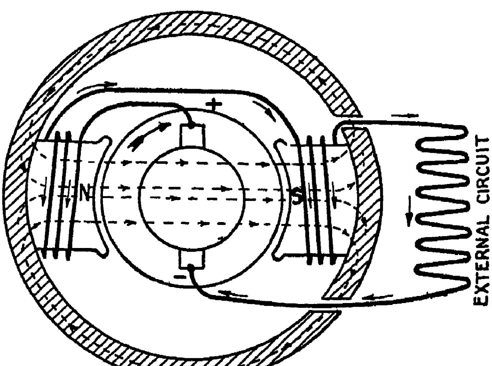


Fig. 499 —Circuits of simple series-wound generator.

generator to generate current when the armature is rotated. For construction and operation of the armature, see Sec. XXI.

In all generators and motors now used as standard equipment on the automobile, the magnetic field is produced by a field winding

of the *shunt* or the *series* type, or a combination of the two. The shunt type of field winding is particularly adapted to the generator, while the series type is especially adapted to the starting motor.

In the shunt-wound generator the field winding is connected across the brushes of the generator, as in Fig. 498, so that about 8 to 12 per cent of the total current generated by the armature is shunted through the field coils for producing the field magnetism. In the series type of winding, Fig. 499, all the current which flows through the armature must also flow through the field winding.

340. The Shunt-wound Generator.—In Fig. 498, which represents a shunt-wound generator, only one armature coil of the simplest type is shown. This armature may be considered as being wound full of similar coils distributed at equal intervals around the armature, each coil being connected to the commutator the same as the one shown. Such an armature is called a drum-wound, open-circuited, two-pole type. The open-circuited-type armature, however, is no longer used for automobile generators, having been replaced by the closed-circuit type. The principle of operation, however, is the same and is much more easily grasped in obtaining an understanding of generator operation.

The principle of operation of a shunt-wound generator is as follows: In Fig. 498 let it be assumed that the armature rotates in a clockwise direction, as indicated by the arrow, and that N and S, marked on the pole pieces, represent the direction of *residual magnetism* (the magnetism left in the field poles and frame), which is through the armature from left to right. When the armature is rotated, the armature coils upon cutting the weak magnetic field produced by the residual magnetism, will set up a slight voltage across the brushes, usually 1 to 1½ volts, making, in this particular case, the upper brush positive and the lower brush negative. This voltage, although low, is sufficient to overcome the resistance of the shunt-field winding which is connected across the two brushes, thereby causing a current to flow from the positive (+) brush through the field winding around the pole pieces to the negative (−) brush. If the magnetic effect of this field current is in the same direction as the residual magnetism, the pole strength will be increased. This, in turn, will increase the magnetic flux through the armature. Since the armature coils will then be permitted to cut more magnetic lines of force per revolution, the voltage across the brushes will also be increased. An increase in brush voltage increases the field strength, which, in turn, increases the armature output. Thus, the armature voltage helps the field and the field helps the armature voltage until the generator reaches its normal operating voltage at the particular speed it is running. This process is called the "building up" of the generator voltage.

341. Generator Residual Magnetism.—In the above description of generator operation, the importance of the *residual magnetism* should be noted. As a matter of fact, it serves as the foundation upon which depends the "building-up" process of the generator. All generators of the electromagnet-field type must contain residual magnetism in the pole pieces and field frame in order to generate current.

Residual magnetism is simply the magnetism which remains in the pole pieces and field frame after the field magnetizing current has died out. The direction of the residual magnetism may be tested by holding a pocket compass near the poles when no current is passing through the field windings or the armature.

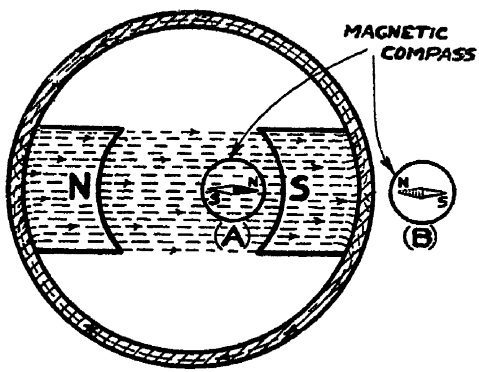


FIG 500—Method of testing generator residual magnetism using a magnetic compass

The same polarity indications will be obtained with the compass needle regardless of whether the compass is held next to the pole face with the armature removed, such as position *A*, Fig. 500, or outside of the field frame, but next to the pole, such as position *B*, with the generator completely assembled.

The north end of the compass needle will point to the south field pole and the south end to the north field pole, respectively, as shown.

Note—*Should the field pole polarity be tested in this manner with the generator running, or while current is flowing through the field winding, the compass needle, when held in position B will, due to the magnetizing action of the field coil, assume a reversed position to that shown in B Fig.* 500, *i e, the south end of the needle will point out the south field pole, while in position A it will register as shown.*

To Give Generator Frame Residual Magnetism.—In case the field frame should lack proper residual magnetism, which may be due to (1) its being

a new machine, (2) to some one testing through the field winding with alternating-current supply, (3) to excessive temperature, or (4) to vibration, the generator may be given residual magnetism by simply sending direct current through the shunt-field winding in the proper direction from either a storage battery or a set of dry cells. The residual magnetism may be reversed by merely reversing the direction of the magnetizing field current. It may also be reversed by the magnetizing effect of the armature coils in case a heavy direct current from a battery is sent through the generator armature with the field winding disconnected or open-circuited.

342. Conditions Which Prevent a Shunt-wound Generator from Building Up a Voltage.—Several conditions are necessary in order that the generator may build up a voltage. Two of the most important requirements are (1) that the field frame has residual magnetism as a foundation on which to build, and (2) that the exciting current in each field coil be in such direction around the pole that it will produce magnetism so as to assist and not oppose the residual magnetism. If it opposes, the voltage cannot build up higher than that produced by the residual magnetism. Common conditions which prevent the generator from building up are:

1. Reversed direction of armature rotation.
2. Opening in shunt-field circuit due to blown fuse, broken wire, loose connection, etc.
3. Heavy short-circuit across the main brushes.
4. Brushes worn, broken, or sticking in their holders.
5. Weak spring tension on brushes.
6. Dirty commutator or high mica which prevents the brushes from making proper contact.
7. Short-circuited, open, or grounded field coils.
8. Short-circuited, open, or grounded armature coils.
9. Field coils connected so as to oppose each other in a two-pole generator.
10. Brushes in wrong position on the commutator.
11. Improperly wound armature.
12. Shunt-field wires reversed.

Note.—For further description of generator troubles see Sec. XXX.

343. Types of Field Windings and Their Characteristics.—Various methods may be used in winding the field poles of a dynamo to suit the purpose for which it is to be used. Figure 501 shows the different ways in which the shunt and series field may be connected on the same type of frame, the markings and arrows

referring in each case to the direction of current when the dynamo is operating as a generator. These markings do not represent the condition when current is sent through the machine, causing the dynamo to operate as a motor. The small diagram to the right of each main sketch is the conventional way of indicating briefly that particular type of D.C. dynamo.

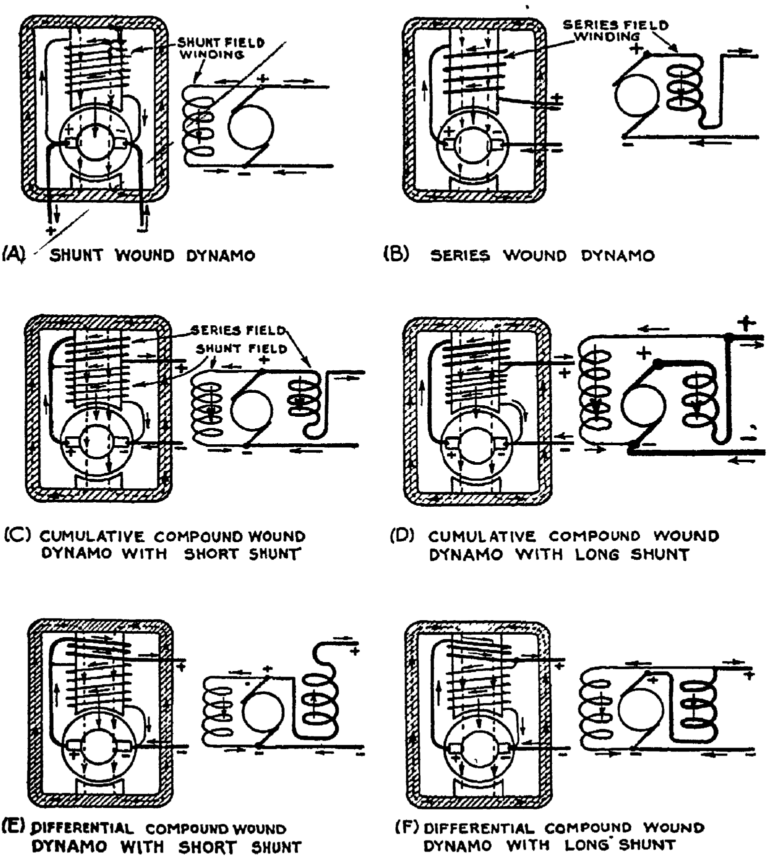


FIG 501.—Types of dynamo field windings.

By applying the right-hand rule for determining the magnetic polarity of an electromagnet, it will be seen that in *C* and *D*, Fig. 501, the shunt and series windings produce magnetism in the same direction and are, therefore, said to be cumulative wound, while in *E* and *F* the magnetism produced by a current flowing

in the series field winding is opposite to that produced by the shunt winding, and therefore the field coils operate differentially.

Note.—It should be remembered from Art 36, Sec II, that, *when two windings wound on the same core operate to create magnetism in the same direction, they are said to be cumulative wound, and when they operate to oppose each other, they are said to be differentially wound.*

Short- and Long-shunt Field Connections.—The shunt field may be connected either inside or outside of the series-field winding. When it is connected inside, as in *C* and *E*, Fig. 501, it is known as a *short-shunt* connection, and when it is connected outside the series, as in *D* and *F*, it is known as a *long-shunt* connection. The principle of each is similar, the difference being that in the short-shunt scheme the shunt-field current does not pass through the series winding, while in the long-shunt connection the shunt-field current must pass through both the shunt- and the series-field coils in order to complete its circuit. In practice, generators represented by types *C* and *D* are not used on the automobile, because the generator must necessarily run at variable speeds and any increase in armature speed and voltage would increase the field strength and, consequently, the armature output would increase to a point where it would over-load the generator as well as over-charge the battery.

The simple shunt type of winding, Figs. 498 and 501*A*, used with a suitable regulator, is the type of field winding generally used for the generator, while the series type of winding, Figs. 499 and 501*B*, is particularly adapted to the starting motor, because all the current passing through the armature must also flow through the field winding, thus producing full field strength and giving the motor the greatest possible cranking power. Types *E* and *F*, Fig. 501, are used in both generators and motor-generators. This type of winding is particularly adapted for motor-generators, since the windings operate differentially, the series field bucking the shunt, thus producing a regulating effect when it is operating as a generator; and cumulative, the series helping the shunt, when current is sent through the machine in the reverse direction, causing it to operate as a starting motor. This action results because *the current will reverse in the series winding and not in the shunt winding if the current is reversed through the dynamo.*

In an automobile generator of the differential-wound type, the series winding, which is commonly known as *reverse series* or *bucking series*, is used only for regulating purposes, the shunt winding being the prevailing winding and controlling the direction of magnetism. The shunt-field winding may be readily distin-

guished from the series, since it consists of a large number of turns of comparatively small wire, while the series winding consists of a comparatively few turns of large wire. Both windings must be well insulated and in some cases are impregnated with a special insulating compound to make them water- and oil-proof.

344. The Reverse-current Cutout.—Two typical reverse-current relays or cutouts are shown in Fig. 502. The details of cutout construction may vary considerably, but the principle of operation is similar in practically all cases. The reverse-current relay or *cutout* is simply an automatic electromagnetic switch connected in the battery-charging circuit between the generator and the storage battery of the electric system. Its function is to connect the generator automatically to the battery when the

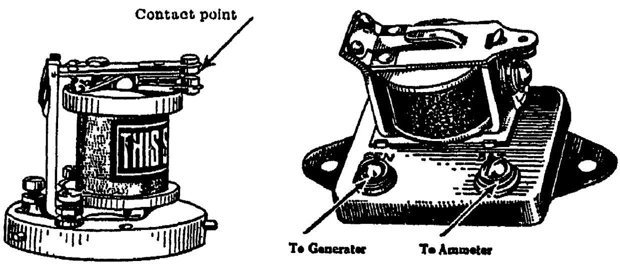


FIG 502—Typical reverse-current relays or cut outs.

voltage of the generator is sufficient to charge the battery, and to disconnect them when the generator is not running or when its voltage falls below that of the battery, to prevent the battery from discharging through the generator windings. In these respects the action of the cutout is very similar to that of the check valve between the pump and the reservoir, as shown in Fig. 476.

A circuit diagram of a typical cutout is shown in Fig. 503, in which it is shown connected with a differentially wound generator and a 6-volt storage battery. The cutout consists of an iron core, a fine shunt winding known as a *voltage coil*, a heavy series winding known as a *current coil*, and a set of contacts. One of the contacts is carried on one end of an iron contact arm that is mounted close to, but held apart from, the core by spring tension, while the other contact is stationary. The contact points are thus held normally open and are closed only when the magnetic

pull of the core on the contact arm is sufficient to overcome the tension of the spring. The spring is adjusted normally, so that the contacts will close when the voltage of the generator has reached from 6½ to 7 volts in a 6-volt system, or 13 to 14 volts in a 12-volt system. These voltages are usually reached, thus causing the cutout to close, at a car speed of from 8 to 10 miles per hour on direct drive or high gear.

Operation of the Cutout.—Referring to Fig. 503, the operation of the cutout is as follows: The voltage coil, which consists of many turns of fine winding, is connected across the generator terminals so as to receive the full voltage of the generator. When the generator attains a speed at which it devel-

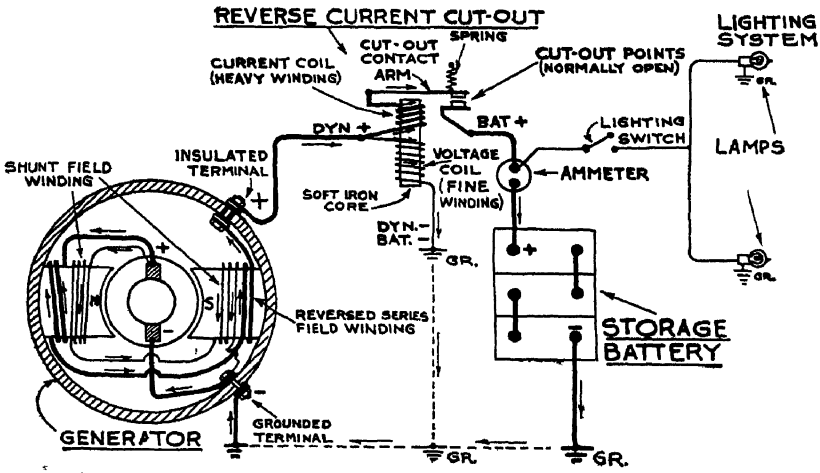


FIG. 503.—Circuit diagram of typical reverse current cut out.

ops, approximately, 6½ to 7 volts, the core is sufficiently magnetized to overcome the spring tension and to close the cutout contacts. This completes the circuit between the generator and the battery through the current coil and the contacts. Since the voltage of the generator at this time is higher than the voltage of the battery, a charging current will flow from the positive (+) terminal of the generator, through the current coil and contacts of the cutout, through the cells of the battery, from positive (+) to negative (−), returning through the ground to the negative terminal of the generator. The charging current flowing through the current coil flows around the core and creates a magnetic effect in it in the same direction as that produced by the voltage coil. The cumulative effect of these two windings greatly increases the magnetic pull on the contact arm and holds the contacts firmly closed.

When the speed of the generator is decreased to a value at which its voltage is lower than that of the battery, that is, below 6 volts, the battery

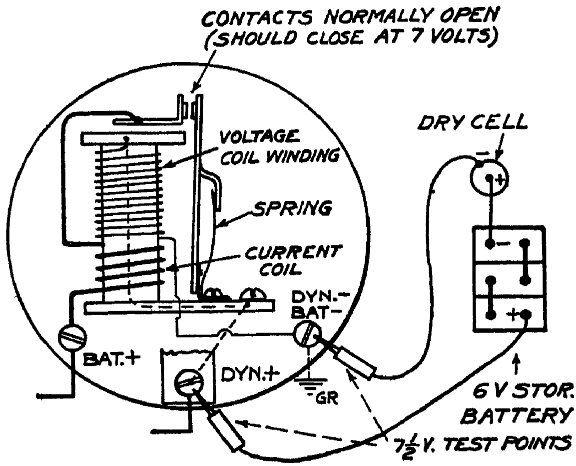
will discharge back through the cutout and the generator in a reverse direction to the charging current. Any reverse current through the cutout will cause the current to reverse in direction in the current coil but not in the voltage coil, thus producing a differential action between the two windings and the core is partly demagnetized. The instant the core demagnetizes slightly, the spring, which is under constant tension, pulls the contact arm away from the core and opens the circuit. The contacts should remain open, thus preventing discharge of the battery through the generator at all times. This may be determined by observing the dash ammeter with all switches "Off." The ammeter is usually connected as shown in Fig. 503, so that it will register the amount of current either charging or discharging from the battery.

345. Method of Adjusting the Cutout.—Two factors must be considered in adjusting a cutout relay to close and to "cut out" or open the generator battery circuit properly: namely, (1) the tension of the spring on the contact arm, and (2) the air gap between the contact arm and the iron core of the relay. The air gap has little or no effect upon the point of "cut out," since the spring tension governs this almost entirely, while, on the other hand, the point of closure or "cut in" is governed by both air gap and spring tension.

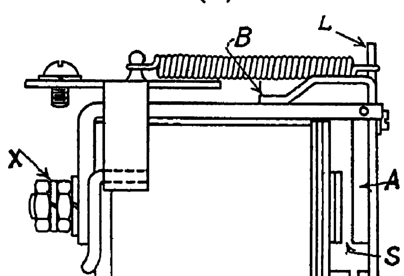
The cutout spring should be adjusted so that the contacts will close when the voltage of the generator has reached 6½ to 7 volts in a 6-volt system, or 13 to 14 volts in a 12-volt system. These voltages are usually reached, causing the cutout to close, at a car speed of from 8 to 10 miles per hour on direct drive, as may be observed by watching the speedometer while increasing the car speed gradually. The cutout should be adjusted to open when the voltage of the generator falls below that of the battery. In fact, it should open when the discharge current, as indicated by the ammeter, is between zero and 2 amp., preferably as near zero as possible to prevent flashing, burning, and sticking of the contact points. The car speed at which the cutout opens should be 2 to 3 miles per hour below the closing speed. This will avoid "chattering" of the contact points when the car is being driven at the critical "cut-in" speed.

The most accurate way of adjusting the cutout to close at the proper voltage is to check it with a low-reading voltmeter connected across either the main generator terminals or brushes or across the voltage coil terminals of the cutout. The generator

speed should be increased gradually and the cutout spring adjusted so as to close automatically at the proper voltage. If the voltage is higher than 7 volts when the cutout closes on a 6-volt system, the spring is evidently too strong or the air gap too wide, while, on the other hand, if the contacts close at too low a voltage, it indicates that either the spring tension is too weak or the air gap too small.



(A)



(B)

FIG. 504.—(A) Shop method of adjusting cutout to close at proper voltage. (B) The Delco cutout relay—illustrating adjustments.

If a suitable voltmeter and method of driving the generator are not available, a 6-volt cutout may be adjusted to close fairly accurately by adjusting the contact spring tension so that the contacts will just close when test leads from either five dry cells or one dry cell in series with a well-charged 6-volt storage battery (giving approximately 7.5 volts) are connected across the voltage coil terminals of the cutout, as in Fig. 504A. The contacts should

close firmly when 7.5 volts are applied, but should remain open when tested with 6-volt leads from the storage battery alone or from four dry cells. In the case of a 12-volt cutout, the cutout spring should be adjusted to allow the contacts to close at 14 volts, or the voltage of seven storage cells in series, but should remain open when tested with leads from 12 volts, or six storage cells.

Air Gap and Contact Adjustment.—The normal air gap between contact arm and core on the average cutout, for example, the Delco, Fig. 504*B*, as indicated by gap *S*, should be 0.025 to 0.035 in. with the contacts closed. This adjustment may be secured by properly bending, with a pair of pliers, the brass stop *B*. The gap between the contacts *P* is usually taken care of by the proper adjustment of gap *S* and should be 0.025 to 0.035 in. when the contacts are normally open. This is important, as the amount of air gap largely determines the cut in point.

The cutout relay contacts are usually of silver, copper, or carbon and should meet squarely so that good electrical contact is made over the entire surface when closed. To clean the contacts or square them up, a strip of fine sandpaper should be drawn between the contacts while they are held lightly closed by the hand.

SECTION XXI

ARMATURE CONSTRUCTION AND OPERATION

346. Armature Construction.—Direct-current generator and motor armatures may be divided into two general classes according to the type of iron core on which the wire is wound, namely, the *ring-wound* type and the *drum-wound* type.

In a typical ring-type armature the core is in the form of a soft-iron laminated hollow cylinder or ring—sometimes a bundle of soft-iron wire—over which the winding is wound with suitable connections to the commutator segments. The ring-type armature has been little used in automotive service and today is practically obsolete.

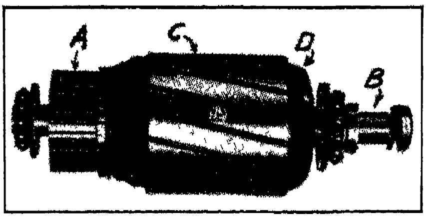


FIG. 505.—Typical drum-wound armature of the automobile type

Typical construction of the drum-wound armature is shown in Fig 505. The essential parts are the commutator A, the steel shaft B, the soft-iron laminations C on the shaft, and the armature coils D. The core is in the form of a solid cylinder or drum, the winding being wound in slots in the surface of the drum—hence, the name *drum wound.* All modern generators and motors use this type of armature. Figures 506A and B show the commutator-end and rear-end views respectively of several typical automobile generator and starting-motor armatures.

The Commutator.—The commutator is built up of copper segments or bars, wedge-shaped and dovetailed, so that when the retaining ring or nut is tightened, Fig. 507, they are held solidly in place. Each commutator bar must be well insulated from its neighbor as well as from the shaft, so that

there will be no current leakage between them. To date, mica has proved to be the best commutator insulation material, since it is capable of withstanding high voltages and temperatures; it has good wearing qualities, and

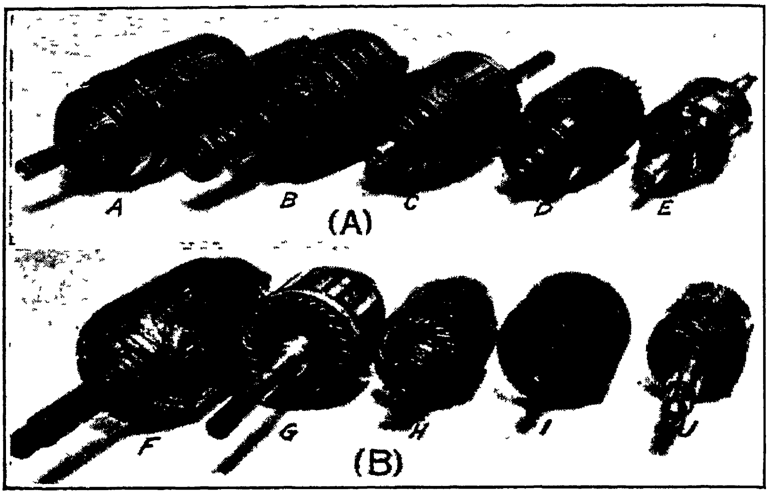


FIG. 506.—Typical generator and starting motor armatures. (*A*) Commutator-end view. (*B*) Rear view.

is comparatively cheap. Other insulating materials, however, have been experimented with, for example, Bakelite, with limited success.

The Laminated Core.—The core or *drum* on which the coils are wound must be made of soft iron, so that the core will magnetize and demagnetize quickly, because, due to the magnetizing action of the field magnetism in passing

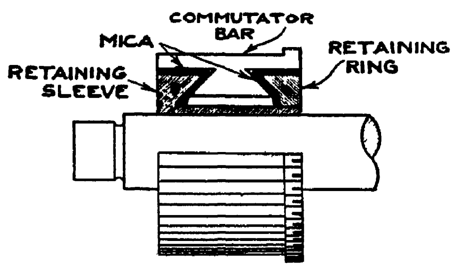


FIG. 507.—Sectional view of typical commutator showing methods of retaining and insulating the segments.

through the armature, the armature core must be remagnetized in a constantly changing direction—and rapidly—when the armature is driven at high speed. Furthermore, the core must be built up of thin, soft-iron laminations, insulated from each other in order to prevent "eddy currents" and heating of the armature. In practice, the core laminations are stamped

out of a special grade of magnetic transformer iron, given a coat of insulating shellac, and then pressed onto the steel shaft so that the notches line up to form the slots for holding the armature coils. A typical armature cut in two, showing the laminated core, is shown in Fig. 508. As may be noted, the laminations are assembled over a key in the shaft to prevent them from

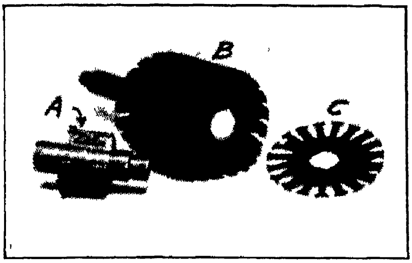


FIG. 508.—Section of typical armature showing laminated core.

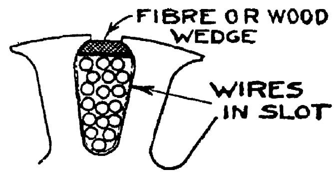


FIG. 509 —Armature slot for generator armature showing wedge for holding coils in place.

turning. The slots, which serve to protect the winding against mechanical injury, may be either spiral or parallel with the shaft. When spiral, the key must be spiral also. In many cases the slots are provided with wooden or fiber wedges, Fig. 509, driven into the slot outside the coils and running the full length of the core to prevent the armature coils from flying out, due to centrifugal force when rotating at high speed.

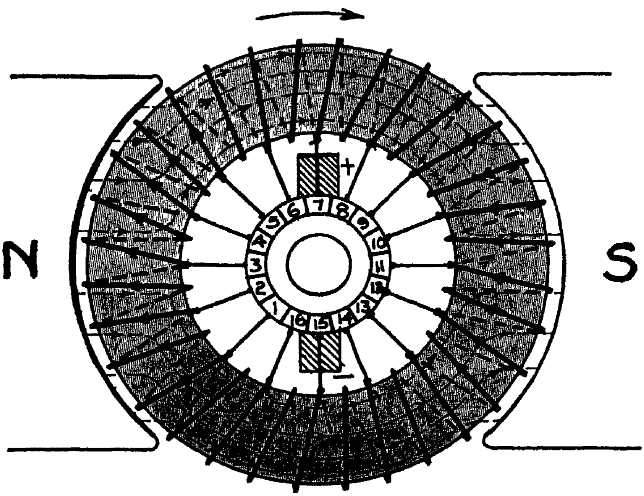


FIG. 510.—Circuit diagram of typical two-pole ring-wound armature.

347. Principles of the Ring-wound Armature.—The commutator-end view and circuit diagram of a typical two-pole, ring-wound, closed-coil type of armature having sixteen commutator

bars is shown in Fig. 510. As explained above, the ring-type armature is no longer used, but because of its simplicity it will be described here in order to make it easier for the reader to understand the principles of the drum-wound types which are quite similar.

Referring to Fig. 510, it will be noted that the path of the magnetic field through the armature follows the iron ring, the magnetic flux entering the ring along the face of the north (*N*) pole and leaving at the south (*S*) pole, as indicated. Since practically all the magnetism follows through the iron ring, and comparatively little passes inside of it, only the outer portion of each coil—that which passes the pole face—actually cuts the magnetic lines of force and generates a voltage, the portion which is across the ends and on the inside of the ring being non-productive.

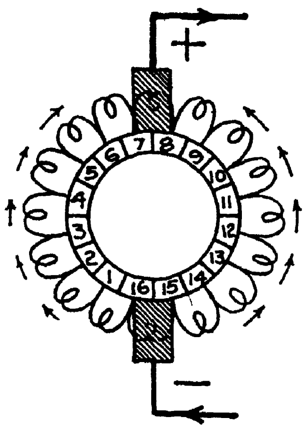


FIG. 511.—Simplified diagram of ring-wound two-pole armature shown in Fig. 510.

It will also be noted, Fig. 510, that each pair of adjacent commutator bars are electrically connected by an armature coil, so that the winding as a whole forms an endless circuit. Assuming that the armature is driven in a clockwise direction and with the field polarity as indicated, a voltage will be induced in the armature coils in an inward direction in front of the north pole and in an outward direction in front of the south pole, as indicated by the arrows. Figure 511 is a simplified diagram of the same armature showing, by means of arrows, the direction of voltage set up between the commutator bars. It is evident from the direction of the arrows that the upper bars, Nos. 7 and 8, will be of positive polarity, while the lower bars, Nos. 15 and 16, will be of negative polarity. The positive and negative brushes must seat on the positive and negative bars, respectively, so that the upper brush seating on bars Nos. 7 and 8 will be positive and the lower brush seating on bars Nos 15 and 16 will be negative. Through the armature, the current flows from the negative toward the positive brush in two parallel paths, one-half of the current output of the armature being generated in one circuit and one-half in the other.

Because the ring-type armature is wasteful of wire, only a small portion of each turn being actually productive, and since the winding offers comparatively high resistance, it is more suitable for high-voltage and low-current output instead of low-voltage and large-current capacity as desired in automotive service. Consequently, this type of armature has given way entirely to the drum-wound type, which possesses the desired characteristics and is less expensive to manufacture.

348. Typical Two-pole Drum-wound Armature with Equal Number of Slots and Commutator Bars.—The circuits of a typical two-pole, drum-wound armature, having 16 slots and 16 commutator bars, are shown in Fig. 512. The same scheme of winding is illustrated by the simplified diagram, Fig. 511. In the drum-wound armature the armature coils lie in slots in the surface of the laminated-iron core and both sides of each coil, turn, or *loop* are active in inducing an electrical pressure. For example, when one side of the coil loop is cutting in front of the north pole, the opposite side of the same coil is cutting in front of the south

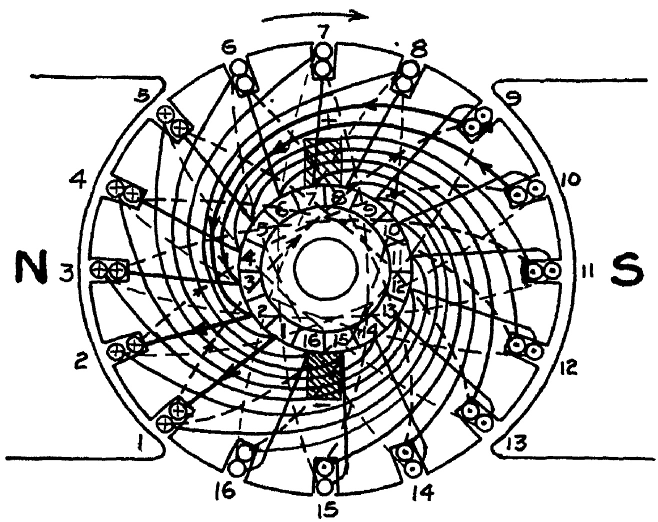


Fig. 512.—Typical two-pole drum-wound armature having 16 slots and 16 commutator bars.

pole, so that the voltages induced in the two coil sides are cumulative.

In the diagram in Fig. 512, 16 slots and 16 bars are shown, and with only one turn or loop of wire in each armature coil, but, as a matter of fact, there may be any number of slots as well as turns per coil. The total number of turns control the voltage produced, while the size of wire and the method of connecting the coils govern the current capacity. As a rule, automobile generator armatures are wound with six to nine turns per coil, using Nos. 16, 17, or 18 copper magnet wire, having usually double-cotton covering or enamel for insulation. The

wires must also be well insulated from the iron core to prevent "grounds" in the winding.

Figure 509 shows a typical arrangement of the wires in each slot for the type of armature shown in Fig. 505. Two coils are wound in each slot, one above the other. These are represented by the 16 pairs of circles on the circumference of the armature, Fig. 512. The coils may be wound by hand directly onto the core, or *form wound;* that is, the coil is wound on a form, shaped, and taped before placing on the core. Generator armatures are usually hand-wound, while starting-motor and starter-generator armatures may be either hand- or form-wound.

Referring to Fig. 512, it will be noted that adjacent pairs of commutator segments are connected through armature coils, the winding forming an endless circuit, as in the ring-type construction. By studying the direction of induced voltages set up in the coils that are cutting lines of force, it will be found that the voltage is inward (away from the reader) in front of the north pole, and outward (toward the reader) in front of the south pole when the armature is rotated clockwise. If the rotation is reversed, however, the direction of induced voltage will also be reversed. The direction of induced voltage in Fig. 512 is indicated in the small circles by a cross (+) and a dot (.), which represent the tail and point, respectively, of an arrow which points in the direction of the induced voltage.

By making a simplified diagram and indicating the direction of induced voltages set up between commutator bars, the same diagram will result as that shown in Fig. 511 for the ring-type armature. It will further be seen that in the drum-wound armature the brushes will be in the same relative positions on the commutator—in contact with the non-productive coil segments—and that there are two parallel circuits through the armature winding, as in the ring-wound armature.

349. Two-pole, Drum-wound Armature with Two Segments per Slot.—In order to decrease the voltages set up between commutator bars, reduce sparking of the brushes, and improve commutation in general, many generator armatures are constructed with twice as many commutator segments as there are slots. The same general method is used in winding and connecting the coils as was used in Fig. 512, except that four coil sides rest in each slot instead of two. Such an armature is shown in Fig. 513*A*, which shows the commutator-end view, while Fig. 513*B* shows a plan development of two adjacent coils. An armature having 12 slots and 24 commutator bars is taken for this example, but the same principles would apply

if more or fewer slots were used, provided the commutator has twice as many segments as slots. In other respects the operation of the armature is practically the same as that shown in Fig. 512.

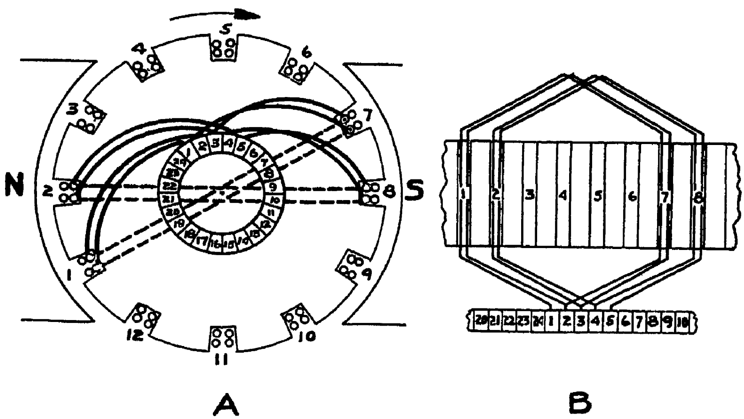


FIG. 513.—Two-pole armature with two commutator bars per slot. (A) Commutator-end view. (B) Plan development.

350. Armature-coil Requirements.—In order to obtain the greatest effect in generating electricity in armature coils, it is evident that one side of the coils must be passing underneath

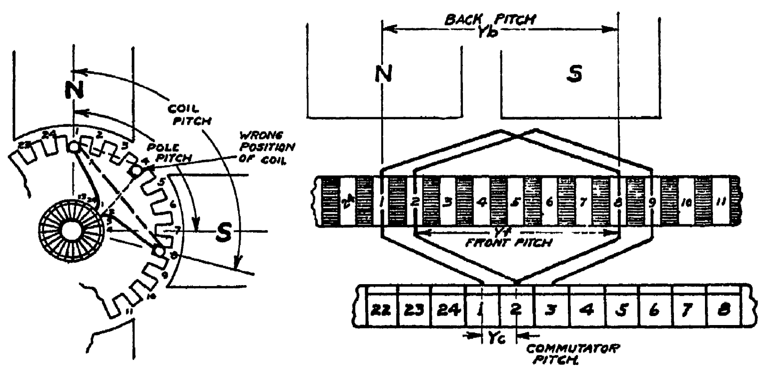


FIG. 514.—Connections for 4-pole lap-wound armature explaining armature winding terms.

a north pole when the other side is passing underneath a south pole, as shown in Fig. 514, which illustrates a four-pole, lap-wound type of winding. This coil arrangement produces an e.m.f. or voltage from front to rear in one-half of the coil and from rear to

front in the other half, the two voltages combining and doubling the pressure.

If the side of the coil which is in slot No. 8, Fig. 514*A*, be placed in slot No. 4 instead, no voltage would be induced in this half because it is in a space where no magnetic lines of force are being cut, consequently only one-half of the coil is active. Furthermore, if in a four-pole machine both sides of the same coil were diametrically opposite, such as would result by installing a two-pole-type armature in a four-pole frame, then opposite sides of the same coil would pass simultaneously under poles of like polarity, and no voltage whatsoever would be produced. Practically the same result would be obtained by attempting to operate a four-pole armature in a two-pole field frame.

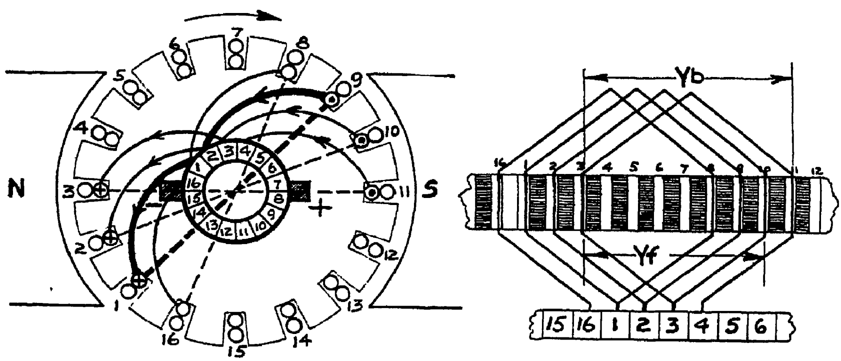


FIG. 515.—Scheme of connecting coils in progressive armature winding

351. Coil Pitch.—From the above it is evident that the sides of the armature coils should be placed on the armature, so that the opposite sides are underneath adjacent poles of opposite polarity. The angular spread of the two sides of the coil is called the *coil pitch.* It is usually expressed in terms of *pole pitch,* which is the angular distance between the centers of two adjacent poles.

If the coil pitch is exactly equal to the pole pitch, it is said to be a *full-pitch winding.* For example, in Fig. 514*B* the winding is slightly greater than a full-pitch winding. If the one coil were placed in slots 1 and 7 and the other in slots 2 and 8, it would illustrate a full-pitch winding.

The coil pitch may also be expressed in terms of slots. In Fig. 514*A*, for instance, the coil pitch is 8, that is, the sides of the coils are placed eight

slots apart. In all cases the coil pitch should be approximately equal to a full pitch, but since it is not always possible to do this, and in some cases it is not advisable, the armature is wound with coils in which the pitch is one or two slots more or less than the full pitch. Hence these windings are known as *long-pitch* and *short-pitch* windings. In Fig 514*B*, *Yb* and *Yf* represent the *back pitch* and *front pitch* respectively.

The coil pitch in any winding is approximately equal to the total number of slots in the armature divided by the number of main magnet poles.

352. Progressive and Retrogressive Windings.—The polarity of the brushes is governed largely by the front and back coil pitches and the scheme used in connecting the coils to the commutator bars. If the front pitch *Yf* selected is less than the back pitch *Yb*, a *progressive winding* will always be obtained. On

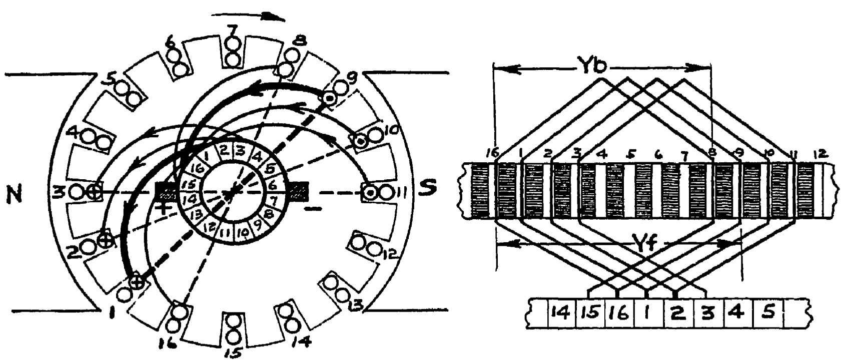


FIG 516 —Scheme of connecting coils in retrogressive armature winding.

the other hand, if the front pitch *Yf* selected is greater than the back pitch *Yb*, a *retrogressive winding* will always be obtained. Examples of the progressive and retrogressive windings are shown in Figs. 515 and 516, respectively. Assuming that the field polarity and direction of armature rotation are the same in both cases, a study of the voltages produced in each will show that the direction of induced voltages between the commutator bars in Fig. 516 is just opposite to that in Fig. 515. This means that the brushes, although located in the same relative positions, will be of reverse polarity. One style of winding has no special advantages over the other.

353. The Four-pole Lap-wound Armature.—In the four-pole type of armature, two methods of connecting the coils are employed, namely, *lap*, or *parallel*, and *wave*, or *series*, so named from the characteristics of the windings.

A typical example of the four-pole, lap-wound armature with progressive windings is shown in Fig. 517. This shows an armature with 16 slots and 16 commutator bars, but a different number of slots and bars could have been used just as well. The armature could also be wound with retrogressive windings without changing the scheme of operation. Furthermore, the armature could have twice as many commutator bars as slots, in which case four-coil sides would lay in each slot, the arrangement being similar to the two-pole armature shown in Fig. 513.

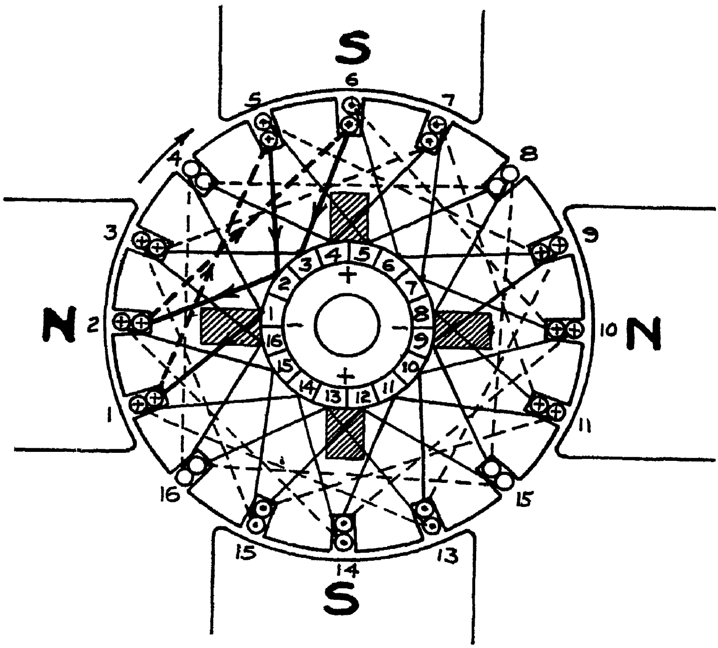


Fig. 517.—Typical 4-pole lap-wound armature.

Referring to Fig. 517, it will be noted that adjacent commutator bars 1 and 2, 2 and 3, 3 and 4, etc. are all connected by armature coils which span four slots or one-fourth of the armature core. Since all adjacent commutator bars are connected through the winding, a simplified diagram may be made for the armature, as shown in Fig. 518. Then, if the direction of induced voltage is indicated by arrows as shown (assuming clockwise rotation), the brush positions and their polarity can be very readily determined. A study of this diagram shows that there are four separate cir-

cuits through the winding, consequently, four brushes will be required and located as shown. With clockwise rotation, the upper and lower brushes will be positive and the two horizontal brushes negative. Both pairs of brushes—those having the same polarity—should be connected so as to operate in parallel as shown.

The outstanding feature of the lap-wound armature is that, owing to its number of parallel circuits and low internal resistance, it is capable of a large current output at low voltage. On the other hand, the employment of as many brushes as there are poles is quite essential and, should any one

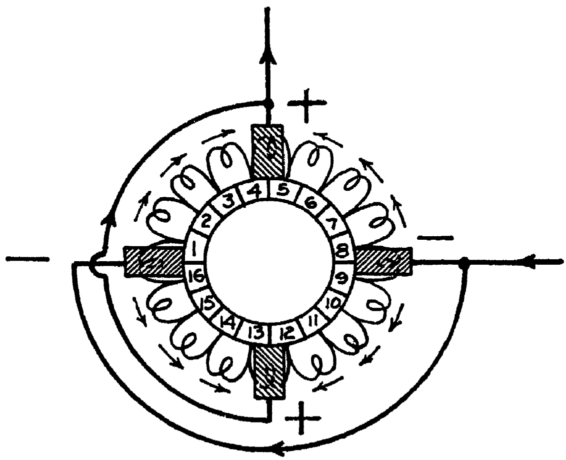


FIG. 518.—Simplified circuit diagram of 4-pole armature shown in Fig 517.

of the four brushes fail to make proper contact with the commutator, two of the circuits through the armature will be interrupted and the current output of the armature will be reduced to approximately one-half of normal at a given speed. Furthermore, with only half of the windings carrying current, and these being on one particular side of the core (depending on which brush is not operating), the armature will be thrown out of both electrical and mechanical balance, due to the unbalanced magnetic attraction between armature and pole pieces.

Because of the reasons outlined above, the lap or parallel style of four-pole winding is not used as much in automotive service as the wave or series type.

354. The Four-pole, Wave-wound Armature.—Two typical four-pole armatures with wave-type windings are shown in Figs. 519 and 520. In Fig. 519 the armature has 15 slots and 15 segments with retrogressive winding, while in Fig. 520 it has 21 slots and 21 segments with progressive winding. The latter

diagram represents the Ford generator armature, which is wound with a special size D.C.C. magnet wire (approximately No. 17½) and 10 turns per coil, the coils being connected as shown.

Through comparison of the lap and wave type of armatures, for example, Fig. 519 with Fig. 517, the differences in the method of connecting the coils will be readily noted. In the lap-wound type, Fig. 517, each coil, in connecting two adjacent commutator bars, passes through two slots only; for example, from No. 1

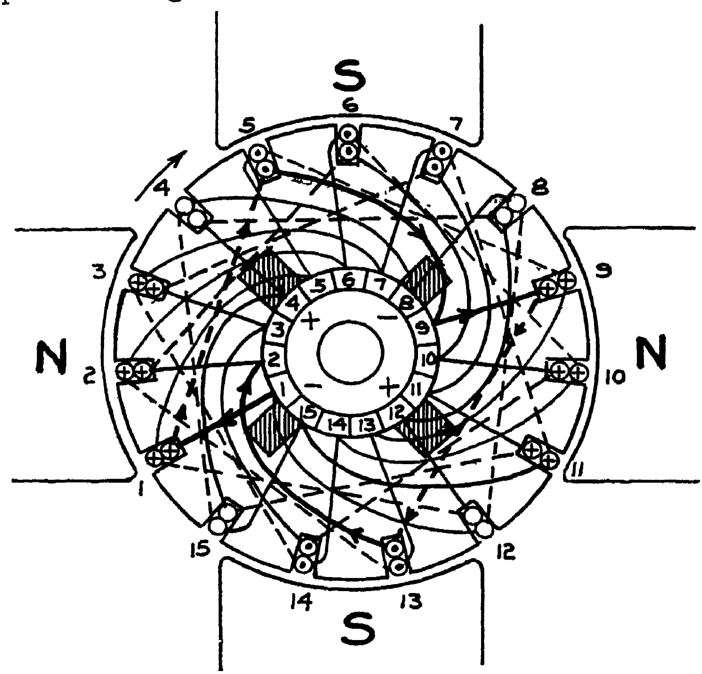


FIG. 519.—Typical 4-pole wave-wound armature having 15 segments and retrogressive winding.

bar, into the bottom of slot No. 1, across the back side of the core to slot No. 5, and forward in slot No. 5, returning to commutator bar No. 2. In the wave or series scheme of connecting the coils, Fig. 519, the coil, in connecting adjacent commutator bars, passes through two slots, then connects to a commutator bar on the opposite side of the commutator, and returns through two more slots before connecting to the adjacent bar. For example, the path of current between bars Nos. 1 and 2, Fig. 519, is from bar No. 1 through slot No. 1, through slot No. 5, to com-

mutator bar No. 9, thence through slot No. 9, returning through slot No. 13 to bar No. 2. The coils connecting the other adjacent bars, such as Nos. 2 and 3, 3 and 4, 4 and 5, all take the same sort of a path, advancing one slot and one segment with one wave around the armature. This necessitates the use of an odd number of slots and segments.

It is also important to note that the commutator bars which lie diametrically opposite are connected through half an armature

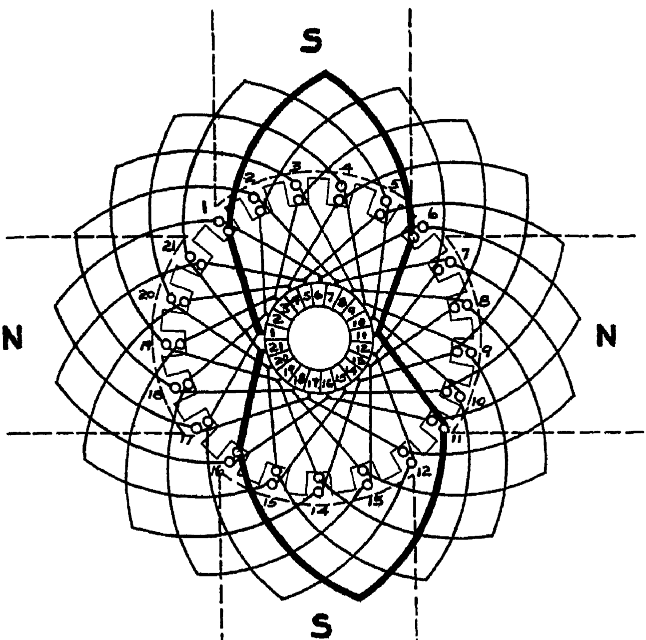


FIG. 520.—Wiring diagram of Ford generator armature illustrating a wave wound progressive winding using 21 slots and 21 segments.

coil, so that they are virtually "shorted" or tied together the same as the brushes of like polarity, Fig. 518. Thus, a four-pole wave-wound armature may be operated successfully with only two brushes set 90 deg. apart, provided the brushes used are of sufficient size and current capacity to handle the current load without undue heating and sparking. Furthermore, the two brushes used may be located in any one of four positions, for example, on the upper side, lower side, left side, or right side, Fig. 519, whichever position affords the greatest accessibility of the brushes, depending upon

the design and location of the generator or motor in which they are used. In the event that all four brushes are used in order to provide sufficient brush area, such as in starting motors where the cranking current is comparatively high (150 to 250 amp.), the opposite brushes should be connected in parallel, as shown for the lap-wound armature, Fig. 518.

Advantages of Wave-type Armature Winding.—A summary of the advantages provided by the wave type of winding in four-pole armatures is as follows:

1. It permits the use of only two brushes set at 90 deg., provided they are of sufficient capacity to handle the current load without undue heating and sparking.
2. It reduces commutator wear and brush maintenance expense to a minimum.
3. The brushes may be located in the most accessible position.
4. It affords the use of third brush regulation on four-, and six-pole generators without undue crowding of the brushes (see Sec. XXII).
5. In generators and starting motors in which all brush positions are used in order to obtain proper brush capacity, the circuits through the armature—and, consequently, the armature balance—will not be affected in case a brush fails to make proper contact.

355. Double-wound Armatures.—In certain models of single-unit starter-generators, for example, the Delco, Fig. 521, the

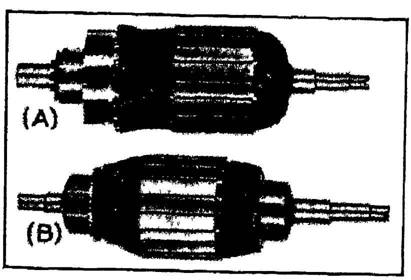


FIG. 521—Delco double-wound armatures (*A*) With both commutators on same end. (*B*) With commutators at opposite ends.

armature is wound with two sets of windings and commutators, one to operate as a generator, the other as a motor. In the Delco armature shown, the heavy outside winding which connects to the large commutator is the motor winding, while the inside winding which connects to the small commutator is the generator winding. In some models, both commutators are located at the

same end of the armature as shown in Fig 521*A*, while in other models they are at opposite ends. As a generator, only the generator windings are operative, while the motor brushes are either lifted from the commutator or disconnected; then, when operated as a motor, the generator windings become inoperative by disconnecting one of the generator commutator brushes. Complete circuits and operation of the single-unit Delco system are given in Sec. XXVI.

In another type of double-wound armature found in the single-unit Wagner installation on the 1913 Studebaker, both sets of windings and commutators are alike, the commutators being located on opposite ends of the shaft. In this system the two sets of windings and commutators are connected so as to operate in series as a generator and in parallel as a motor, the series-parallel connections being made by a suitable rotary-type starting switch.

In both the Delco and the Wagner double-wound armatures, the two sets of windings must be insulated from each other and from the armature core. They must, therefore, be tested independently for defects.

356. Armature Reactions.—The magnetic and electrical reactions which occur in the armature core and windings when the armature is driven under load, particularly at high speed, play a very important part in governing its operating characteristics. For example, the intermediate or *third-brush* principle of generator regulation (see Art. 372, Sec. XXII) depends entirely for its operation upon the reactions which exist in the armature when it is rotated and generates a current. Consequently, in order to understand the principles of third-brush regulation, the causes of these armature reactions must first be thoroughly understood.

357. Cross-magnetization and Field Distortion in Generator Armature.—It has been found that, when the armature is made to rotate between the pole pieces, causing the various armature coils to cut the magnetic lines of force, the side of each armature loop which cuts in front of the north pole will induce a voltage in one direction, while the opposite side of the same loop cutting in front of the south pole will induce a voltage in the opposite direction with respect to the armature and pole pieces. In Fig. 522, let the small circles (shown equally spaced around the circumference of the

armature) represent so many armature coils, each coil being connected to the commutator segments in such a way that when the armature is rotated in the clockwise direction the upper brush will become positive (+) and the lower brush negative (−) polarity. With the armature rotating in this direction, the current induced in each coil as it passes in front of the north pole will be generated to flow in or away from the reader, while, in front of the south pole, the current will be generated to flow out or toward the reader. The direction of the current flowing in each coil that is generating is indicated by either a cross (+) or a dot (.), depending upon whether the current is leading away from or toward the reader. The cross and dot represent the tail and point, respectively, of an arrow pointing in the direction of current and should not be confused with the plus (+) and minus (−) signs representing positive and negative polarity.

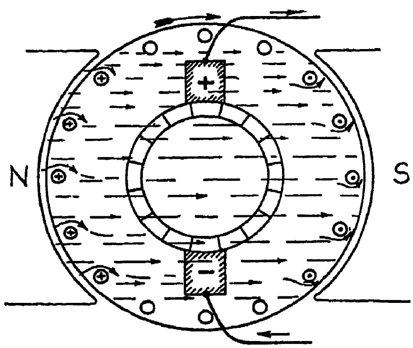


FIG. 522.—Distribution of magnetic flux through generator armature at low speed.

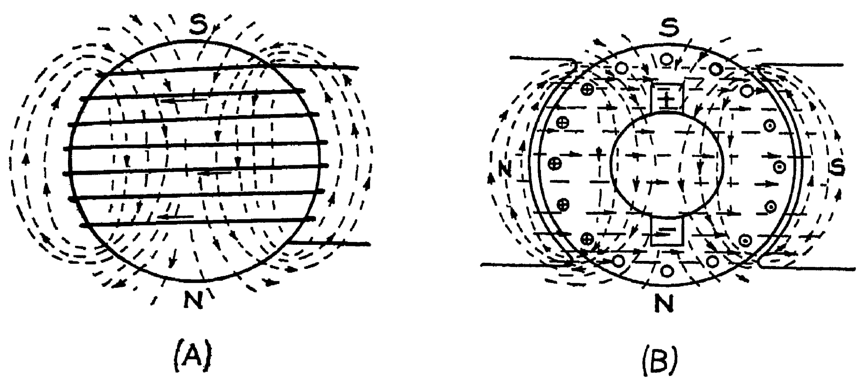


FIG. 523.—Cross magnetization of generator armature due to generated current.

When the armature is delivering current to an external circuit, such as the battery and lighting system, the effect of the current flowing in different general directions in the armature coils on opposite sides of the armature will be to magnetize the armature

in a cross-direction, thus making one side of the armature core north and the other south. This effect is much the same as if a wire were wound on an iron cylinder and a current passed through it, as shown in Fig. 523*A*. In the armature, this cross-magnetizing force will be through the armature and pole pieces at right angles to the magnetic field produced by the field winding as shown in Fig. 523*B*. By a study of this figure it will be seen that at the lower corner of the north pole piece and at the upper corner of the south pole piece the magnetic lines of the two fields are in opposite direction, while at the upper corner of the north pole piece and at the lower corner of the south pole piece the magnetic lines are in the same direction. This will cause a reaction between the two magnetic fields resulting in the magnetic lines being crowded to the trailing corners of the poles, thus distorting the general path of the magnetic flux across the armature as shown in Fig. 524. The amount of this field distortion will depend upon the speed of the armature and the strength of the current (the battery-charging and lighting current) flowing in the armature winding. Owing to the shifting of the magnetic flux and the consequent shifting of the points of maximum voltage on the commutator, the brushes should be set slightly ahead, as shown, to have them in the best running position at the normal operating speeds of the armature.

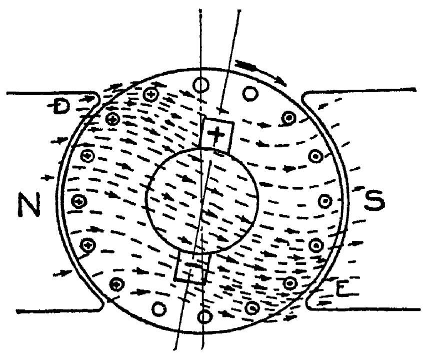


FIG 524.—Distortion of magnetic flux through generator armature due to speed of rotation and armature current.

358. Field Distortion in Motor Armature.—The principles of the simple motor were explained in Art. 40. Referring to Fig. 44, it will be noted that, operating as a motor, the magnetic field through the armature is distorted in a direction opposite to the direction of the armature rotation instead of in the same direction, as in the generator. This means that the best running position of the brushes on the commutator will be slightly behind the normal neutral brush line instead of ahead, as explained for the generator. In *starter-generators*, where the same armature and

commutator function both as a generator and as a motor, it is evident that, if the brushes are set in the best running position as a motor they will not be in the best position as a generator. In such cases the brushes are set to favor the operation as a generator—since the generator runs continuously—and the machine is built of such size that it will have sufficient cranking power as a motor, in spite of the fact that it does not operate with highest efficiency.

Counter E.M.F. Produced in Motor Armature.—An important factor which controls the current consumption of a motor armature is the countervoltage, or e.m.f. (electromotive force), which is produced in the armature windings as the armature rotates Although the armature is actually operating as a motor, the windings are rotating in and cutting a magnetic field, with the result that a voltage is generated in the windings, as in the ordinary generator. The direction of this generated voltage opposes the direction of the motorizing current, thus it is termed *countervoltage*, or *counter e.m.f.* This counter e.m.f. increases as the armature speed increases, thus decreasing the current consumption of the armature, the effect being similar to the gradual addition of resistance in the motor-armature circuit as the speed increases. This explains why a starting motor consumes the maximum current immediately after closing the starting switch and draws less and less current as the armature attains speed.

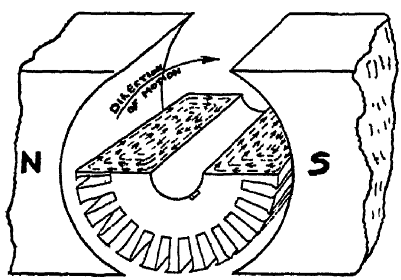


FIG. 525.—Solid core armature showing eddy currents.

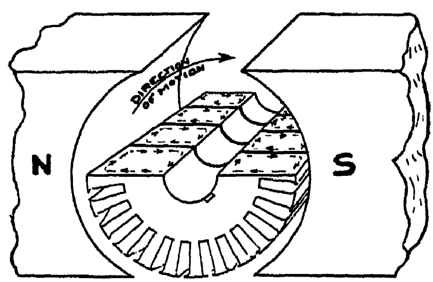


FIG. 526.—Eddy currents in an armature with four laminations.

359. Eddy Currents.—As previously explained, the core used for armatures is built up of thin, soft-iron laminations. If a core of solid iron should be used, its rotation in a magnetic field would result in cross-electric currents, known as *eddy currents*, being set up in the core, as indicated by the arrows in Fig. 525, because when rotated the outer metal of the core cuts more magnetic lines of force per second than that next to the shaft, due to the greater radius of rotation.

Since the eddy currents flow in short circuits through the core and do not contribute any current to the external circuit, their existence should be eliminated as far as possible to prevent armature heating and loss in efficiency. This is accomplished through the use of thin laminations insulated from each other by paper, shellac, or rust, in order to decrease the electrical conductivity between the laminations, and thereby break the eddy currents into numerous small ones, each being confined to one lamination, as shown in Fig. 526. This figure illustrates a core having four laminations. In practice, however, many laminations are used, each being $\frac{1}{64}$ to $\frac{1}{32}$ in. in thickness.

Note.—In automobile generators the armature should not be allowed to rub the pole pieces (as may happen when bearings are worn or the armature shaft is bent), otherwise the edges of the laminations may become shorted, causing excessive heating and burning out of the armature winding. Usually the only satisfactory remedy for an armature with shorted laminations is to replace it with new, since it would again burn out if rewound.

SECTION XXII

METHODS OF GENERATOR REGULATION

360. Regulation of the Generator.—Since all generators used on the automobile increase in voltage and in current output with an increase in engine speed, some method of generator regulation is necessary to protect the generator windings and brushes against excessive current over-load, and the battery from over-charge. Several methods of regulation are possible, such as (1) controlling the speed of the armature through mechanical governors, (2) controlling the strength of the field current, which, in turn, controls the strength of the field magnetism that is cut by the armature windings, and (3) controlling the current output by a mechanically operated rheostat (adjustable resistance unit) placed in series with the battery, the resistance of the battery-charging circuit being increased or decreased as the armature speed increases or decreases. The first and third methods have not proved satisfactory. The various methods of regulation now in use operate on the principle of controlling the field magnetism, decreasing the field strength as the armature speed increases, and increasing field strength as the armature speed decreases, in an endeavor to hold the generator output constant. The regulation of the field magnetism may be effected in three ways:

1. Through reverse-series (differential) field winding, in which a series winding opposes the shunt winding more and more as the generator speed and output increase.
2. A vibrating-type relay, in which a resistance unit is cut in and out of the shunt-field circuit to obtain either current or voltage regulation, or both.
3. The third-brush principle of regulation, which depends upon the reactions which take place in the armature and the resulting distortion of the path of field magnetism through the armature, as the generator increases in speed and current output.

361. Regulation of the Generator through Mechanical Governors.—Generator regulation through mechanical governors is one of the oldest schemes for controlling the generator output.

The governor may be used: (1) to control the speed of the armature by a slipping clutch, an example of which is found in the Gray & Davis, type C-1 generator, shown in Fig. 527; (2) to increase the resistance in the shunt-field circuit as the speed increases, as used in the 1915 single-unit-type Delco system,

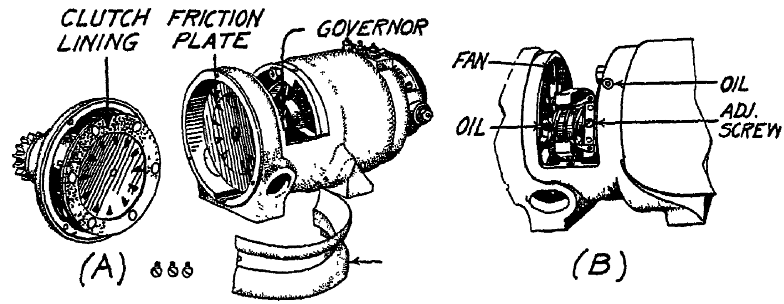


FIG. 527.—Gray and Davis generator, Type C-1, regulated through mechanical governor. (A) Showing clutch disassembled. (B) Internal view of governor.

shown in Fig. 528, and (3) to control the charging rate by the governor arm cutting resistance into the battery-charging circuit, the principle employed by the Vesta magnet-type generator, Fig. 529.

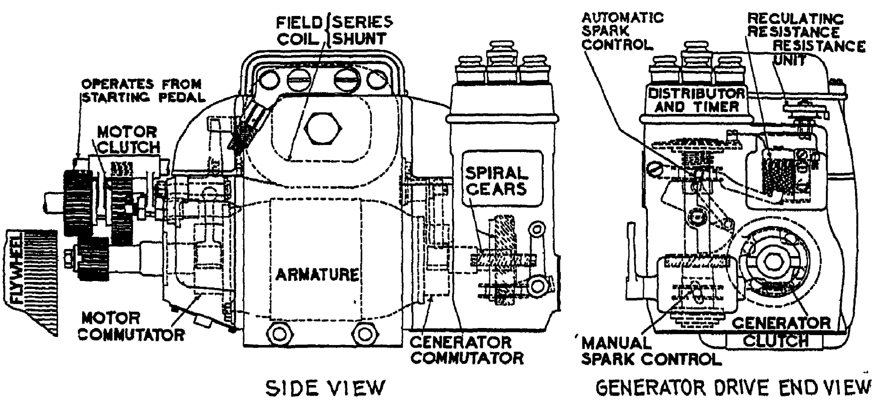


FIG. 528.—Delco motor-generator regulated as a generator by governor operated rheostat (1915).

As a whole, the mechanical-governor methods of generator regulation have not been a great success, and consequently they are little used today. The G. & D. slipping-clutch-type generator gave good results so long as the clutch was in proper adjust-

ment and the generator was installed so that it cooled properly. However, the constant slipping of the clutch to obtain constant armature speed after the predetermined regulating speed was reached, say 1,500 r.p.m. of the armature or 18 to 20 m.p.h. of the car on high gear, caused continuous wear of the slipping clutch members, and the production of considerable heat which must be dissipated through proper ventilation, thus requiring frequent adjustments. The charging rate of this type of generator may be increased or decreased by increasing or decreasing the tension of the governor springs.

In the governor-type Delco generator, Fig 528, and the Vesta generator, Fig. 529, it was found difficult to maintain the proper balance between governor-spring tension and resistance to give the proper charging current characteristics at high speeds. In the Vesta generator, the low-speed contact made by the governor contact arm opens the charging circuit entirely, thus serving as a cutout However, should the governor fail to return the contact arm to the cutout position when the generator voltage falls below the battery voltage, the battery may discharge through the armature, with the result that, due to the magnetizing effect of the armature coils, the field magnets are partly demagnetized, thus materially reducing the output of the generator and causing insufficient or no charging of the battery thereafter. This same trouble is experienced with practically all permanent-magnet-type D.C. generators if the battery is allowed to discharge through it, that is, running it as a motor.

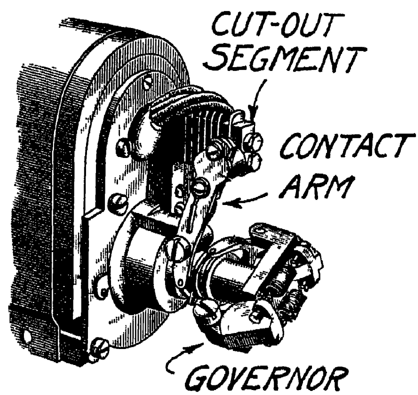


FIG. 529.—The Vesta magnet type generator showing governor for controlling resistance in the charging circuit.

362. Regulation of the Generator through Reverse-series Field Winding.—The reverse-series or *bucking* field method of generator regulation is one of the simplest methods, from the standpoint of construction and operation. It is simple because the regulation is taken care of by the inherent action of the field winding, which does not involve any wearing or moving parts, and requires no adjustment. Two typical methods of connecting the shunt- and series-field windings to obtain this regulation were shown in *E* and *F*, Fig. 501, Sec. XX, *E* showing the short-shunt

and *F* the long-shunt method of connecting the windings. The principle of each, however, is similar, the difference being that in the long-shunt connection the shunt-field current must pass through both the shunt- and the series-field coils to complete its circuit.

A typical application of the reverse-series method of generator regulation is found in the Auto-Lite two-pole laminated frame-type generator shown in Fig. 530. It will be noted from Fig. 531 that the field winding is of the long-shunt type, in that one end of the shunt winding is connected at the outer end of the series. The circuits of the cutout relay are similar to those described for Fig. 503, Sec. XX.

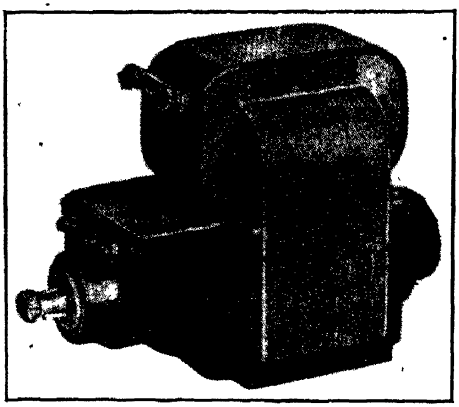


FIG. 530.—Auto-Lite 2-pole generator, Model G.

The principle of operation, Fig. 531, is as follows: As the generator builds up a voltage, two circuits are established between the brushes, one through the shunt-field winding, magnetizing the field frame north and south, as shown, the other through the voltage-coil winding of the cutout relay. Both of these circuits lead through the series-field winding and complete their circuits as indicated by the arrows in the diagram. At the speed at which the cutout closes, connecting the generator with the battery, the generator voltage is only slightly above that of the battery and a small current will flow through the battery in the charging direction. The path of this current is from the positive (+) brush through the reverse-series field winding, over the cutout contacts through the current coil, through the ammeter and

battery from positive (+) to negative (−), returning through the ground to the negative (−) brush of the generator. Since this charging current flows through the reverse-series field winding in a reverse direction to the current flowing in the shunt winding, a demagnetizing force is produced in the field frame which increases with an increase in generator speed and current output. The result is a weakening of the field magnetism, as the armature speed increases, so that after the maximum desired charging rate is reached, which is usually 12 to 14 amp. at 18 to 20 m.p.h., the current output of the generator will never exceed the predetermined amount, even though the generator is driven at a high rate of speed.

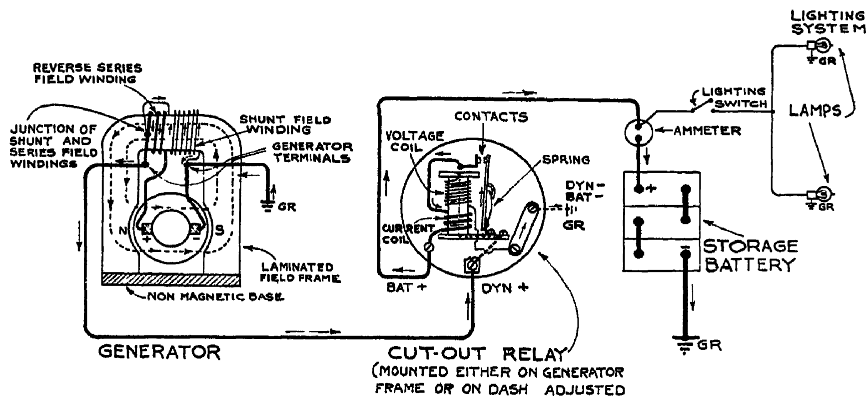


FIG. 531.—Circuit diagram of Auto-Lite generator and cut out relay showing reverse-series field method of generator regulation

The regulation depends upon the current flowing in the reverse-series winding. Consequently, since this regulating current constitutes the current supplied by the generator to the battery and to the lighting system (in case the lights are turned on), it is essential that an *open circuit* should not occur in the battery-charging circuit, otherwise the charging current will be obstructed and the regulation of the generator destroyed. Precautions, therefore, must be taken to see (1) that the cutout closes properly, (2) that the connections of the generator, the cutout, and the ammeter are clean and tight, and (3) that the battery terminals are always tight and free from corrosion. If an open circuit should occur in the charging circuit, thus destroying gen-

erator regulation, the voltage will become excessive, usually resulting in damage to the field and armature winding and to the winding of the cutout. Should an open occur in the circuit at either battery terminal, the lights may also be burned out, in case they are turned on with the generator running at speeds above 15 to 18 m.p h., or above the speed at which regulation should begin. If, for any reason, the car is to be operated with the battery disconnected, the system should be protected against excessive voltage by connecting a piece of copper wire across the two generator terminals. This short-circuits the brushes through the reverse-series field winding and prevents the generator from building up a voltage.

In generators of the reverse-series field-regulated type, there is usually no convenient method provided for increasing or decreasing the charging rate without changing the proportion of turns either in the shunt- or the series-field winding. By decreasing the number of turns in the series field, the maximum generator output can be increased, while increasing the number of turns will decrease the output.

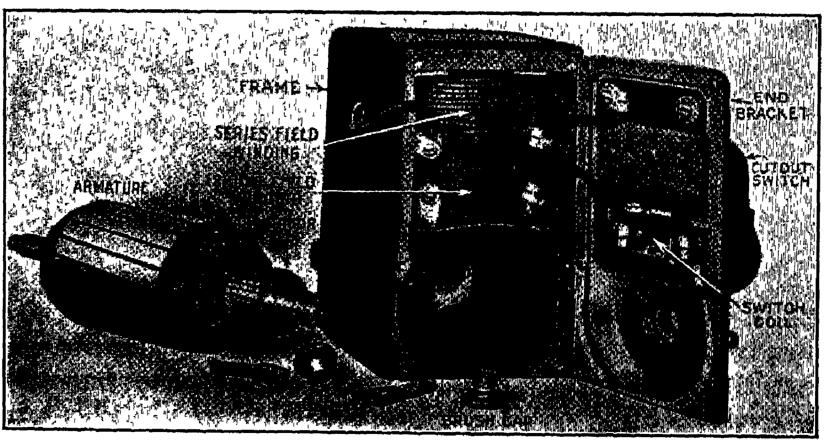


FIG. 532.—Westinghouse 2-pole reverse-series type generator.

363. The Westinghouse Reverse-series type Generator.—The Westinghouse two-pole square-type generator, shown in Fig. 532, as introduced on 1915 cars, is another example of reverse-series regulation. The internal circuit diagram of this generator is shown in Fig. 533. The outstanding feature of this generator is that the lighting-switch wire is connected to the inner end of

the reverse-series field coil, so that at low speeds the lighting current passes through the series-field winding, causing the series winding to operate cumulative with the shunt field, thereby increasing the field strength and boosting the generator output with the lamp load on. The two fields will continue to operate cumulative until the generator output equals the lamp load, or as

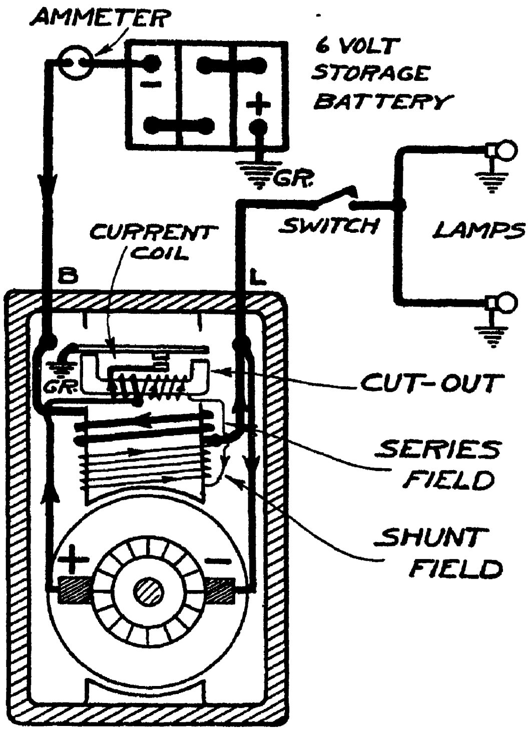


FIG. 533.—Circuit diagram of Westinghouse 2-pole generator illustrating reverse-series regulation.

long as the ammeter shows discharge. At the critical speed at which the generator output balances the lamp load, that is, the battery is not charging or discharging and the ammeter shows zero, no current is passing through the series field and the generator operates as a plain shunt-wound generator; but as soon as the generator output exceeds the lamp load, and the battery is receiving charge, the charging current flowing through the series winding in a reversed direction to that of the lighting current

causes the series-field magnetism to oppose that of the shunt and the generator receives reverse-series regulation.

Thus, the capacity of the generator is increased during night driving when the lamp load is on and the demand for current is greatest. Furthermore, during day driving, when little current is being used, regulation begins at a lower speed and the generator output is considerably reduced at normal driving speeds.

364. Regulation of the Generator Current through Vibrating-type Relay.—A circuit diagram of a typical vibrating-type regulator used for obtaining constant current regulation of the generator is shown in Fig. 534. The regulating relay consists of a soft-iron core, around which is wound a single winding; a current coil of

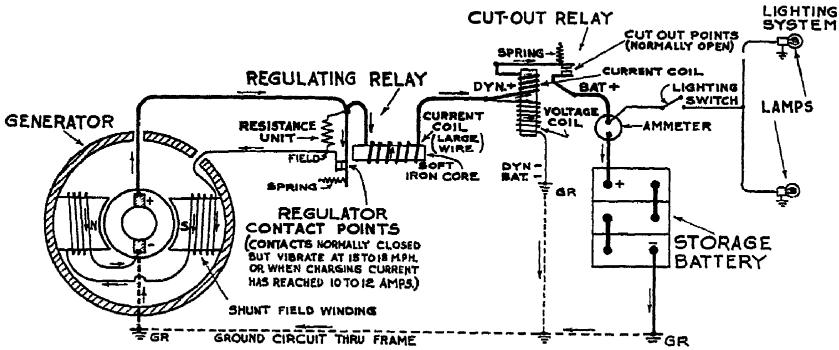


FIG. 534 —Circuit diagram of typical vibrating type regulator to obtain constant current regulation of the generator.

heavy wire; a set of regulator contact points held normally closed by spring tension; and a resistance unit which is connected across the two regulator contact points.

This regulating relay controls the current output of the generator as the generator speed increases, by cutting a resistance intermittently in and out of the shunt-field circuit as the regulator points open and close, due to the varying magnetic pull of the core. The resistance unit is connected in the shunt-field circuit but is normally short-circuited by the regulator contacts, one of which is mounted on a soft-iron contact arm to which is attached the spring for holding the points in contact. The generator, when driven by the engine, builds up as a simple shunt-wound generator, the shunt-field current flowing as indicated from the positive (+) brush through the contact points, through the field

winding to the negative (—) brush. When the speed and the voltage of the generator are increased sufficiently to cause the cutout to close, thus completing the battery-charging circuit, the generator will begin to charge the battery, the charging current flowing through the regulator winding. This current flowing through the regulator winding will magnetize the core which, in turn, will exert a magnetic pull on the regulator contact arm tending to pull the contacts apart. When the battery-charging current becomes a predetermined amount, usually 10 to 12 amp., the core becomes magnetized sufficiently to attract the contact arm, overcoming the pull of the regulator spring. This separates the contact points, and the resistance unit, being inserted in series with the shunt-field winding, causes the field strength to weaken. This causes the armature voltage to drop and, consequently, the charging current to decrease. When the current decreases to a predetermined amount, say 9½ amp., the current coil does not magnetize the core sufficiently to overcome the pull of the spring, thus allowing the spring to close the contacts. With the contacts closed, the resistance unit is once more short-circuited and the full field strength is restored, causing the charging current to increase again. Under operating conditions, the contact arm vibrates automatically and rapidly at such a rate as to keep the generator output constant. As a result, the generator will never charge the battery above a predetermined amount (for example, 10 amp.), no matter how high the speed of the car. At all speeds greater than the predetermined speed (about 15 m.p.h. in practice) the generator will produce a substantially constant current. This will be true regardless of whether the battery is fully charged or completely discharged.

This method of generator regulation is termed *current* regulation, since the current output of the generator is made use of in regulating itself. It is, therefore, very important that no opens occur in the charging circuit, as there would then be no current flowing through the current coil to operate the vibrating points and all regulation of the generator would be destroyed. Thus, to operate a car equipped with this type of system with the battery disconnected, the field wire should be disconnected, thereby preventing the generator from building up a voltage.

As in all systems controlled by a vibrating-type relay, the charging rate of the generator is adjusted very easily. To increase the maximum charging rate, the spring tension of the vibrating contact arm should be increased slightly and, to decrease the maximum charging rate, the spring tension should be decreased, care being taken to see that the generator does not become over-loaded.

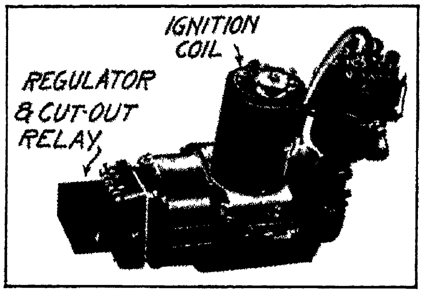


FIG. 535.—Remy generator with current type regulator, Model 161.

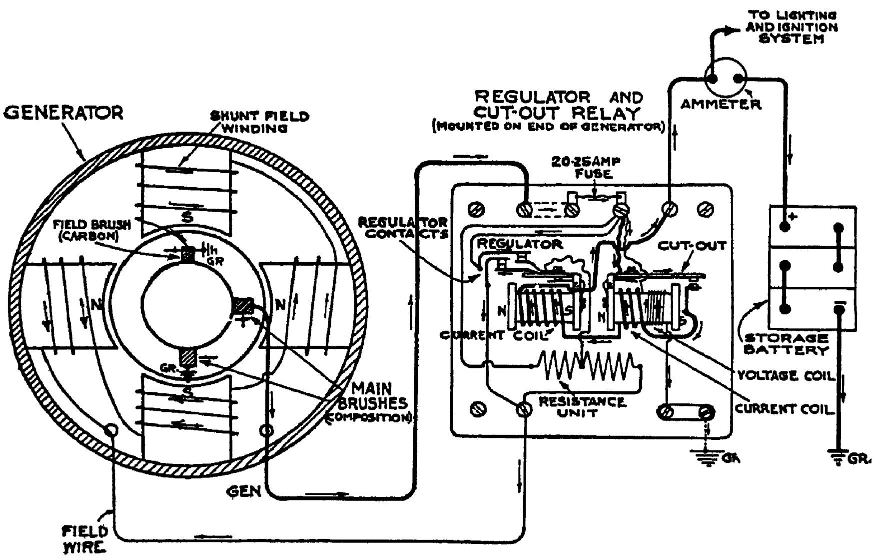


FIG. 536.—Internal circuit diagram of Remy generator with relay regulation.

365. The Remy Generator with Relay Regulation.—The Remy generator, Fig. 535, is a typical example of current regulation through a vibrating relay. In this model the regulating relay and cutout unit are mounted on one end of the generator frame. It may also, however, be mounted separate from the generator on the back of the dash.

A circuit diagram of the generator, the regulator, and the cutout relay is shown in Fig. 536. As will be seen from the diagram, the regulator and the cutout compose two independent relays mounted side by side.

The regulator consists chiefly of an electromagnet, an arm operating on hardened-bronze pivots, two sets of contact points held normally closed, and a resistance unit The contact points are of silver, the two on the arm being mounted upon springs. The cutout is of similar construction, except that a single set of contacts is used, the points of which are held normally open. The regulator core has a single winding—a current coil—while the cutout has the usual voltage and current windings.

Operation of Cutout and Regulator.—When the engine, and, consequently, the generator are running fast enough to produce sufficient voltage for battery charging, the cutout closes through the action of the voltage coil and connects the generator with the battery, the charging current flowing through the current coils of both the cutout and the regulator in series, as shown in Fig. 536. When the generator is running at a speed lower than that required for maximum output, the regulator contact points are held together by a spring under the contact arm, the current supplied to the generator field passing directly through both of these points in series. As the speed of the generator tends to cause its output to rise above the maximum predetermined value, the charging current, which is flowing through the current coil on the regulator core, magnetizes the core to such an extent that it pulls the arm down. This pulls the contact points apart, forcing the field current, which has heretofore been passing through these points, to pass through the resistance unit. This added resistance in the field circuit decreases the field current and, in turn, decreases the output of the generator. This reduces the energizing effect of the electromagnet, permitting the spring to force the contact points together again, thereby cutting the resistance out of the field circuit. The generator output then starts to build up again and the operation previously described is repeated. A continuous repetition of this operation sends a pulsating current to the generator field and holds the output of the generator at practically a constant value. Thus, the regulator is of the constant-current type, previously illustrated in Fig. 534.

The generator is protected by a fuse fitted to the relay regulator base. In case the battery should become disconnected, through either accident or neglect, this fuse will burn out, opening the shunt field and rendering the generator inoperative and damage-proof.

366. Regulation of the Generator Voltage through Vibrating-type Relay.—A circuit diagram of a typical vibrating-type regulator to obtain constant voltage regulation of the generator is

shown in Fig. 537. Although the construction of this relay does not differ materially from that of the current-type regulator, the principle of operation is somewhat different, in that in this system the voltage of the generator is regulated automatically instead of the current output, as in the current type of regulator. By comparing Fig. 537 with Fig. 534, it will be seen that the principal difference in the two relays is in the winding of the core. In the voltage type of regulator the charging current does not flow through the regulator winding. The winding of the core consists of a voltage coil of fine wire, the two ends of which are

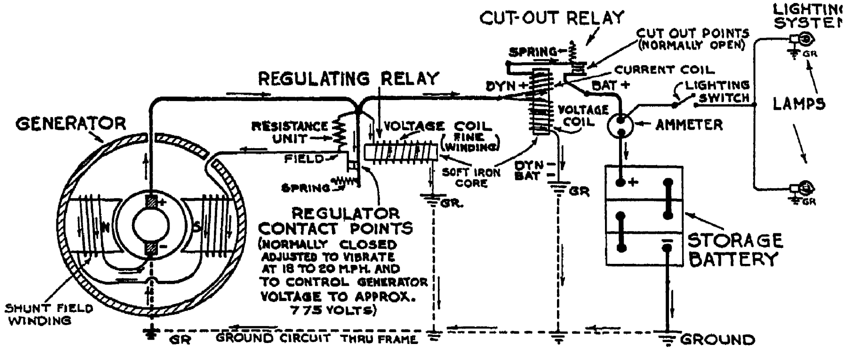


FIG 537.—Circuit diagram of typical vibrating type regulator to obtain constant voltage regulation of the generator

connected across the generator brushes and in parallel with the battery, instead of in series with it as in the current type of regulator. The core, the regulator points, and the resistance unit, however, are practically the same.

Principle of Operation.—The current flowing in the voltage coil and the resulting magnetic pull of the core on the regulator contact points depend upon the voltage developed by the generator. In a 6-volt system the regulator is adjusted to hold the generator voltage constant at 7.5 to 7.75 volts, usually the latter. With increasing generator speed, the voltage will tend to rise above 7.75 volts. If, however, this value is exceeded by a small amount, the increased magnetic pull of the core on the contact arm, due to the current flowing in the voltage coil, will overcome the spring pull and the contact arm will be drawn toward the core, thus opening the contacts and inserting the resistance in the generator-field current. This added resistance in the field circuit decreases the current in the field winding, and the voltage developed by the armature tends to drop below the normal value of 7.75 volts.

If the voltage drops slightly below normal, the pull of the spring on the regulator contact arm predominates and the arm moves away from the core,

closing the contacts. This short-circuits the resistance unit and permits the field current to increase. This cycle of operation is repeated rapidly, maintaining the generator voltage constant at all speeds above the critical value at which it develops 7.75 volts with the resistance cutout of the field circuit. Since the generator is regulated to maintain a constant voltage, even though an open should occur in the charging circuit, it is possible to operate the lamps *off* of the generator, with the battery disconnected, without danger of burning out the bulbs.

It is obvious that increasing the tension of the regulator spring will increase the constant voltage which the generator will maintain. Under no circumstances should the regulator-spring tension be increased in an attempt to have the generator charge at a higher rate at low speed. The generator cannot begin to charge until the cutout closes. The closing of the cutout is independent of the action of the regulator, provided the regulator-spring tension does not become weaker than that of the cutout. Since the cutout closes after the generator reaches a speed at which it develops 6.5 to 7 volts, no adjustment of the regulator or cutout can change the speed characteristics of the generator. Furthermore, increasing the tension of the regulator spring, so that the generator will develop a constant voltage in excess of 7.75 volts, will usually result in excessive current to the battery, over-charging it or causing the generator to over-heat, with the possibility of burning it out.

367. Characteristics of Voltage Regulation.—In the constant-voltage type generator the amount of current generated depends upon the state of charge of the storage battery and the amount of lamp load in use. When the generator reaches a speed at which it develops its normal voltage, there will be no further increase in voltage with increasing speed; the voltage will be maintained constant at all loads, and at all higher speeds. The voltage measured across the terminals of the storage battery is variable and depends upon the state of charge of the battery. With a discharged battery the voltage is a minimum and the voltage increases in value as the charge continues.

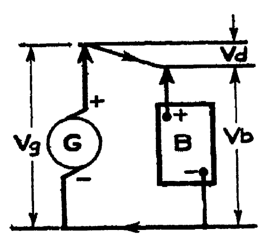


FIG. 538.—Graphical representation of constant-voltage charging.

During the time the generator is connected to the battery, the difference in pressure between the two is the pressure available for sending current into the battery, as illustrated graphically in Fig. 538. Thus, if the battery voltage V_b is 6.2 and the generator voltage V_g is 7.75, the pressure V_d available for sending current through the battery will be V_g minus V_b, or 1.55 volts.

In a discharged battery, the difference in pressure between the generator and the battery will be relatively great, so that a comparatively high-charging current will pass from the generator to the battery. As the charge continues, the voltage of the battery increases, so that the difference in pressure between the generator and the battery is continually diminishing. With a fully charged battery, the pressure is very nearly equal to that of the generator, the difference between the two being very slight. As this slight difference in pressure is all that is available for sending current into the battery, the charging current will be small. The current generated, therefore, is variable and is independent of speed. In practice, the charging current varies from a maximum of usually 15 to 20 amp. for a discharged battery, to a minimum of usually 4 to 6 amp. in a fully charged battery.

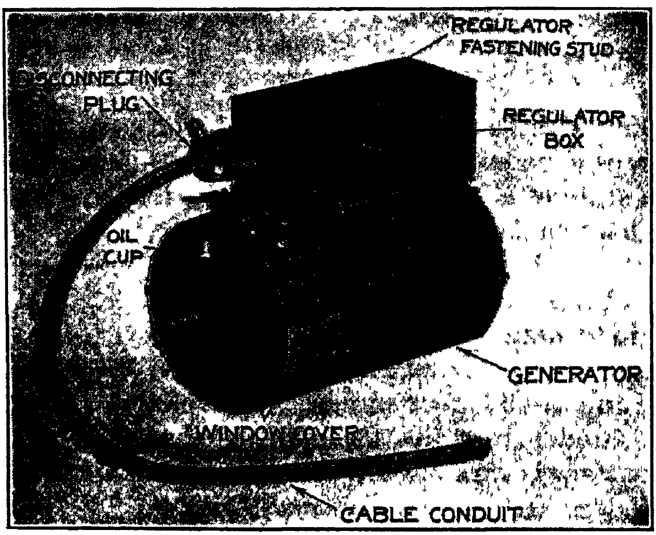


Fig. 539.—Bijur constant-voltage generator and regulator.

368. The Bijur Generator with Constant-voltage Regulation.— The Bijur constant-voltage type of generator, Fig. 539, is a practical application of the constant-voltage method of regulation. The circuit-wiring diagram of the generator, the regulator, and the cutout is shown in Fig. 540. The cutout, the voltage regulator, and the resistance unit are fastened on a fiber board

as a unit and mounted in an aluminum box which fits on top of the generator. This box is provided with three-split connecting pins which fit into three receptacles in the generator, so that the mechanical act of putting the regulator box in place on the generator makes all the necessary electrical connections between the generator, the cutout, and the regulating mechanism. A knurled-headed screw passing through the box to the generator frame also helps to hold the box in place.

Connection from the generator to the battery, Figs. 539 and 540, is made through a wire and plug which fits into the receptacle at one end of the relay box. There are two spring plungers in this receptacle which make contact with two contacts in the disconnecting plug. This plug is designed so that it can be

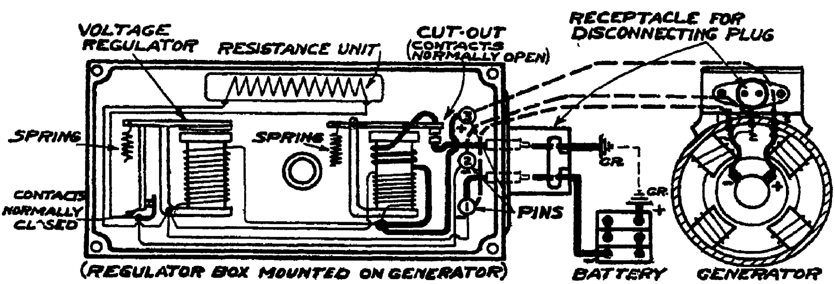


FIG. 540—Circuit diagram of Bijur voltage regulator and generator.

rotated through a small angle, after it is in place, for reversing the connections of the contacts. By reversing the plug, the generator polarity is also caused to reverse, which, in turn, reverses the polarity of the regulator vibrating points. This equalizes any transfer of metal on the regulator points, thereby decreasing their tendency to pit and, consequently, greatly increasing the life and the efficiency of the regulator. About every 500 miles of travel it is recommended that this disconnecting plug be reversed in order to reverse the generator polarity. By merely reversing the plug, the polarity of the generator reverses automatically when the engine is started.

369. Combined Current and Voltage Regulation of the Generator through Vibrating-type Relay.—A circuit diagram of a typical vibrating-type relay for obtaining both constant current and voltage regulation of the generator is shown in Fig. 541.

By comparing this figure with Figs. 534 and 537 it will be seen that the winding of the relay is merely a combination of the other two, the core being wound with both a current and a voltage winding. This construction combines the cutout and the regulator into a single relay. The cutout points, Fig. 541, are mounted on one end of the core, and the regulating points on the other end, the two sets of contacts being operated by independent springs.

The operation of the regulating part of this relay is practically the same as that of the voltage-type regulator, except that, in addition to the controlling of the generator voltage, as effected by the voltage winding, the generator current output is also controlled

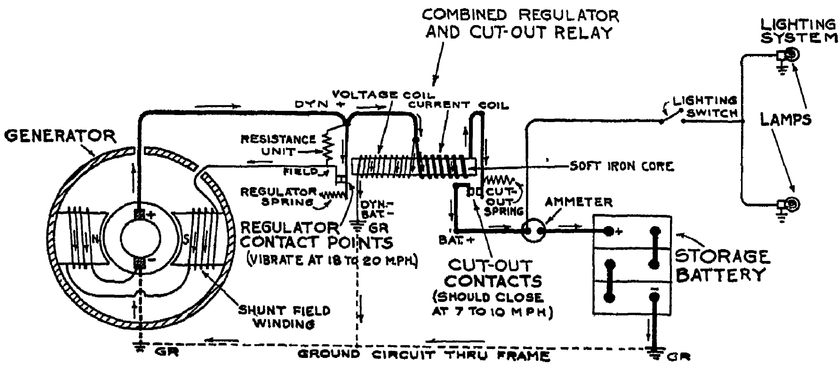


FIG. 541.—Circuit diagram of typical combination vibrating type regulator and cut out to obtain constant current and voltage regulation of the generator

by the charging current flowing through the current coil. It will be seen from the diagram that both the windings carry current around the core in the same direction, the magnetizing force of both assisting each other in operating both the regulator and the cutout contact points. By combining the current and the voltage windings in this manner, the combined characteristics of both the constant-current and the constant-voltage methods of regulation are partly attained. The proper functioning of the relay, however, depends upon the combined effect of both windings; consequently, if for any reason the cutout points do not close to make proper contact, or an open should occur at some other point in the charging circuit, such as due to a burned-out ammeter or a corroded battery terminal, no current will flow through the

current coil, thus leaving the generator to depend entirely on the voltage winding for regulation. The generator voltage will, in this event, be somewhat higher than normal when the car is driven at high speeds. If this condition continues, the regulator and generator windings may be damaged. On the other hand, if the voltage winding should become broken or disconnected, the cutout cannot close and the entire regulation of the generator will be destroyed. Precautions should be taken, therefore, to prevent such opens occurring in both the voltage coil and the charging circuits, otherwise damage may result through the burning out of the generator and regulator windings.

As a safeguard, in case the car is to be operated with the storage battery removed, the shunt-field wire connection to the regulator should be disconnected thereby preventing the generator from building up In many installations the regulator is mounted on top of the generator frame, in which case it is often more convenient to remove the entire regulator while the battery is disconnected, and to replace it when the battery is again installed.

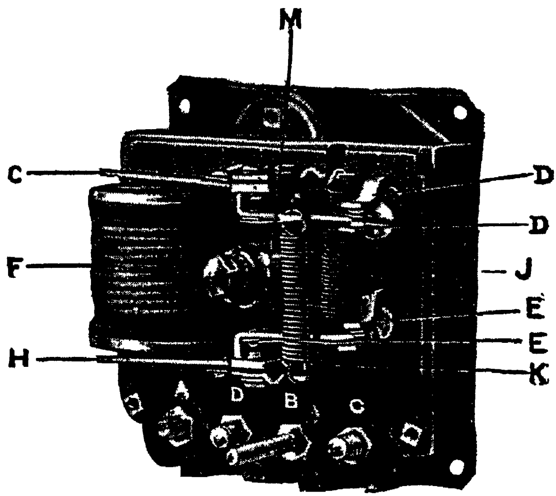


FIG. 542.—Ward-Leonard automatic controller, Type CC.

370. The Ward-Leonard Regulator.—The Ward-Leonard regulator, type CC, Fig. 542, is a typical vibrating-type regulator and cutout by which both the voltage and the current output of the generator are controlled. The wiring diagram of this regulator is shown in Fig. 543. The voltage-coil winding is represented by N, the current coil by F, the cutout contacts by D, the regulator contacts by E, and the resistance unit by M.

When the generator is driven at a speed sufficient to close the cutout and to charge the battery, the current output of the generator passes through the current coil *F*. This is in the same direction around the core as the current flowing in the voltage winding. When the charging rate reaches the predetermined amount, say, 10 amp., the magnetic pull of the core is sufficient to attract the arm *H* and separate the regulator contacts *E*, thereby inserting the resistance *M* in series with the shunt field. This weakens the field and reduces the generator voltage and current

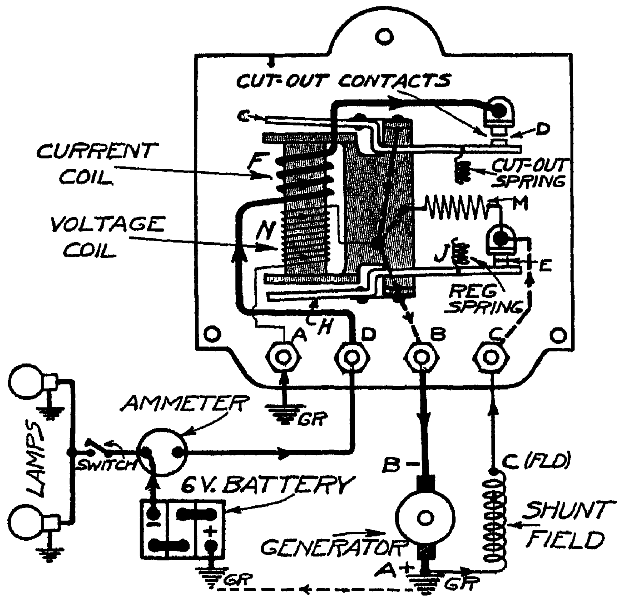


FIG. 543.—Circuit diagram of Ward-Leonard cut out-regulator, Type CC.

output. When the current decreases to, say, 9 amp. the coil *F* is not strong enough to hold the arm *H* against the action of the spring *J*, and the contact at *E* is made again, short-circuiting the resistance *M*. This increases the field strength. The generator output also tends to increase, but when it is increased to 10 amp. the contacts *E* open again, inserting the resistance *M*. This same cycle of operations of inserting and short-circuiting the resistance *M* is repeated as the generator speed is increased. Under operating conditions, the arm *H* vibrates automatically and rapidly at such a rate as to keep the voltage and the current

output of the generator constant when the engine is running at a fair speed.

371. The Westinghouse Generator with Vibrating Regulator.—The Westinghouse generator, No. 400, together with the regulator,

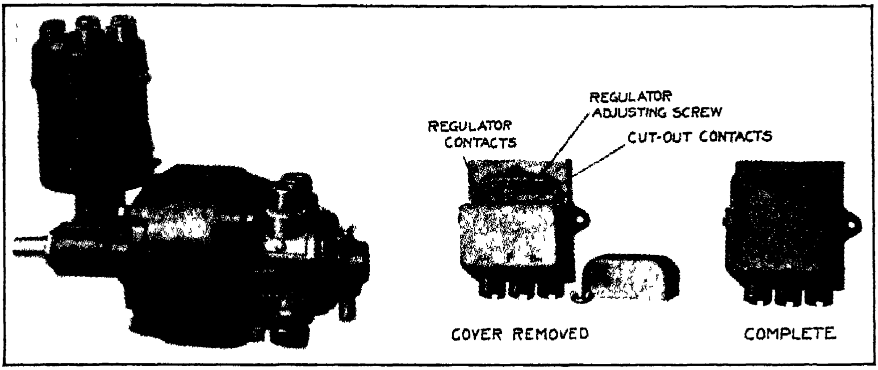


Fig. 544.—Westinghouse generator, type 400, with voltage regulator.

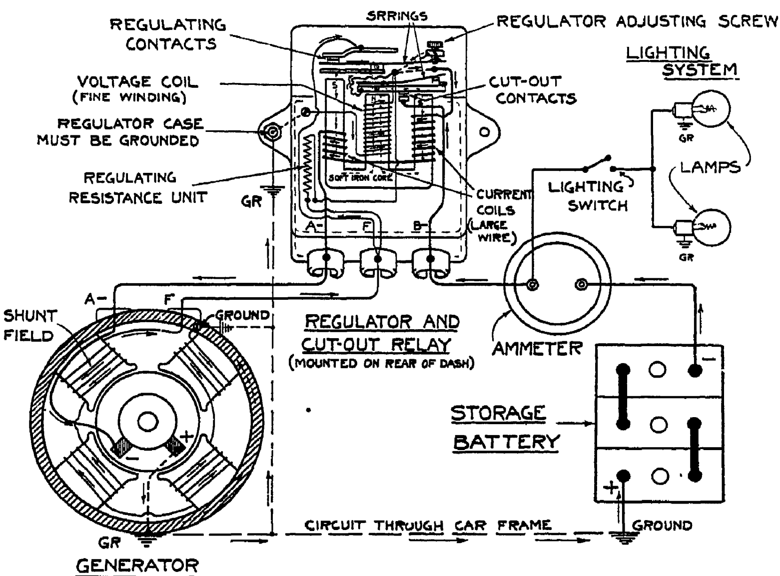


Fig. 545.—Circuit diagram of Westinghouse generator, type 400, with vibrating regulator.

Fig. 544, is typical of the Westinghouse equipment of the relay-regulated type introduced on many 1916 and 1917 cars.

The relay, Fig. 545, performs two functions: (1) that of a cutout which automatically connects and disconnects the generator from

the battery when the generator is driven above or below a predetermined speed, and (2) that of a regulator which automatically keeps the generator voltage and the current output at a predetermined value after the cutout has connected the generator circuit to the battery. Each function of the relay is performed by its individual element. The successful operation of the regulating function, however, depends upon the proper operation of the cutout. The core of the relay is of the three-legged, or W, type. It has two magnetic circuits, one for operating the cutout contact arm, the other for operating the regulator points, as shown by the dotted lines through the core.

Cutout.—When the generator is being operated at a speed below the predetermined cut-in speed, the contacts of the cutout are open, the voltage of

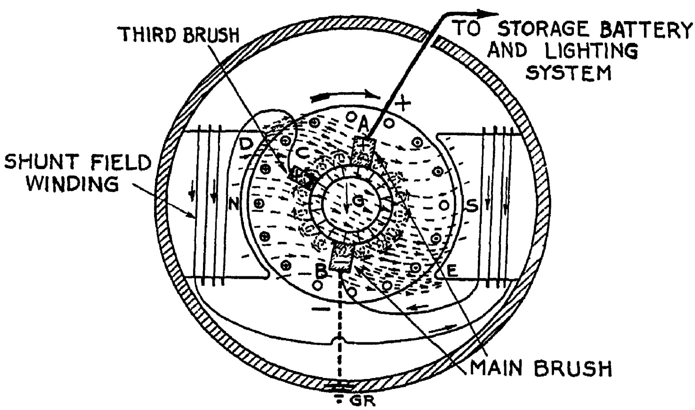


FIG. 546.—Diagram showing principle of third brush regulation.

the generator being below that of the battery. When the generator speed reaches the cut-in speed, the contacts are closed, connecting the generator to the battery circuit. The cut-in speed varies from 5 to 10 m.p.h. on high gear, depending upon the gear ratio and the wheel diameter of the car.

The cut-in speed of the generator can be observed by running the car and allowing it to increase in speed slowly, observing on the speedometer the speed at which the car is running when the cutout contacts close. This is indicated by a slight movement of the ammeter needle toward the "Charge" side.

The relay is constructed so that the cutout operates to disconnect the generator from the battery circuit at a speed slightly below the cut-in speed. This allows the cutout portion of the relay to keep the circuit closed, instead of opening and closing it continuously when the car is being run at speeds close to the cut-in speed. This disconnecting of the generator from the

battery circuit, when the generator voltage is below the battery voltage, insures that the battery will not be discharged through the generator.

Regulator.—The regulator, Fig 545, is of the combined current- and voltage-regulating type. The shunt field of the generator is connected by a wire to the middle terminal *F* on the relay, the field circuit being completed through this wire, the regulator contact points, and the wire which connects to the terminal *A*

When the generator is operating below the cut-in speed, the regulator contacts are closed and remain closed, short-circuiting the resistance unit until the generator armature is revolving at a speed sufficient to produce the maximum charging rate for the battery When, due to the increased speed and current output for which the generator is set, the strength of the magnetic circuit through the regulating side of the relay is increased by the action of the voltage and the current coils sufficient to attract the regulator contact arm, the contacts are opened This cuts the regulating resistance into the shunt-field circuit and reduces the field strength which, in turn, causes a momentary drop in voltage, so that the contacts close again. This continuous opening and closing of the contacts is so rapid as to be imperceptible to the eye, and it holds the voltage and current fairly constant.

The maximum current output of the generator can be increased or decreased by increasing or decreasing the spring tension on the regulator points. This may be done by turning the regulator adjusting screw on the top of the relay shown in Figs. 544 and 545. Care should be taken in making this adjustment to make sure that the generator does not become overloaded. The usual maximum charging rate for this generator should be fixed not to exceed 10 to 12 amp.

372. Principles of Third-brush Regulation.—The wiring and the arrangement of brushes for a typical two-pole third-brush type of generator are shown in Fig. 546. Let *A* and *B* represent the main brushes which connect to the storage battery and lighting system, and *C* the third brush, which connects to one end of the shunt-field winding. The dotted loops connecting the commutator segments represent the various armature coils (which are also represented by the circles) and the arrow on each loop indicates the direction of the induced current in the loop.

As explained in Art. 357, Sec. XXI, when the generator is running at a low speed and little or no current is flowing in the armature winding, the magnetic field produced by the field winding is approximately straight through the armature from one pole piece to the other, and the voltage generated by each armature coil is practically uniform during the time the coil is under the pole pieces. In a generator of the 6-volt type, in which 7 to 7½ volts are actually generated between the main brushes when charging

the battery, it is evident that, with the third brush in the position shown, approximately 5 volts would be generated between *B* and the third brush *C*, since these brushes span only this relative proportion of the commutator segments, and, consequently, collect only a part of the total voltage generated. This is similar to the voltages obtained from the five dry cells shown in Fig. 547, in which it may be assumed that the voltage of each cell corresponds to that of one armature coil. It is also evident that wire *C* may be of positive or negative polarity, depending upon whether it is compared with *B* or *A*, respectively.

In respect to *B*, Fig. 546, the third brush *C* is positive polarity, so that if one end of the shunt-field winding is connected to *C* and the other end to *B*, the field current will flow from *C* through the winding to *B*, as indicated by the arrows, the voltage being approximately 5 volts when the full voltage is 7 to 7½ volts.

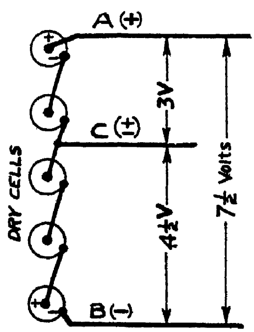


FIG. 547.—Explaining brush polarities indicated in Fig. 546.

As the generator speed and charging rate increase, the charging current flowing through the armature winding produces a cross-magnetic field in the direction of the arrow *G* (see Art. 357, Sec. XXI). This distorts the magnetic field produced by the shunt-field winding, so that, instead of the magnetism being equally distributed under the pole pieces, it becomes denser in the pole tips marked *D* and *E* and weaker in the other pole tips. With this distortion of the magnetic field, the armature coils no longer generate an equal voltage while passing under the different parts of the pole. Although the voltage across the main brushes *A* and *B* remains near 7 to 7½ volts, the greater part of it is generated by the coils which connect to the commutator between brushes *C* and *A*, as these coils cut the denser magnetic field. The coils which connect to the commutator between the brushes *B* and *C* are for the most of the time in the region of the weak field, thus generating a lower voltage. The result is a dropping off of the voltage across the brushes *B* and *C*, and an increase across *A* and *C* as the speed and the charging rate increase. Since the voltage

across brushes B and C is the same as that applied to the shunt-field winding, it is apparent that the field strength is weakened. As this drop in field strength takes place more and more as the speed of the generator increases, the result will be an automatic regulation of the current output.

Adjusting the Charging Rate.—In practically all generators which have third-brush regulation, provision is made for changing the maximum charging rate to suit the conditions under which the generator is operated. This can be done by moving the position of the third brush on the commutator. It is evident that the maximum voltage applied to the field winding will depend upon the number of active armature coils spanned by the brushes which collect the field current. Thus, moving the third brush in the direction of the armature rotation increases the maximum current delivered to the shunt-field winding and, consequently, the output of the generator, while moving it in the opposite direction decreases the output. Whenever this brush is moved in either direction, care should be taken to see that it makes perfect contact with the commutator. It should usually be seated to the commutator by drawing a piece of fine sandpaper between the brush and the commutator with the sanded side next to the brush. If this is not done, the brush may seat imperfectly and the charging rate increase or decrease when the brush seats properly through wear, depending on which edge of the brush makes contact with the commutator bars after adjustment Whenever the charging rate is increased, and after the brush is properly seated, the maximum charging rate should be noted. This should be done by slowly speeding up the engine and noting the highest reading on the ammeter. In most generators it should not exceed 15 to 18 amp. and then decrease with further increase in speed.

373. Characteristics of Third-brush Regulation.—One of the outstanding characteristics of generators with third-brush regulation is that the charging rate of the generator increases gradually with an increase in speed, up to a car speed usually of 25 to 30 m.p.h. After this, the charging rate falls off as the speed continues to increase, so that at speeds of 40 to 50 m.p.h. the charging rate is approximately one-half to two-thirds of its maximum value. This is an advantage, in that the maximum charging rate is obtained at normal driving speeds, while at high speeds, such as during cross-country touring, when the starter and lights are seldom used, the decreased charging rate tends to prevent over-charging of the battery and over-heating of the generator. Typical curves showing the variation of the field and charging currents are shown in Fig. 548.

Since the third-brush type of generator depends upon the charging current flowing through the armature winding to produce the field distortion necessary for regulation, it is obvious that the generator is of the current-regulated type. It must, therefore, have a complete charging circuit available through the battery at all times, otherwise regulation is destroyed In this respect it is like the other methods of regulation, except for the voltage-regulator

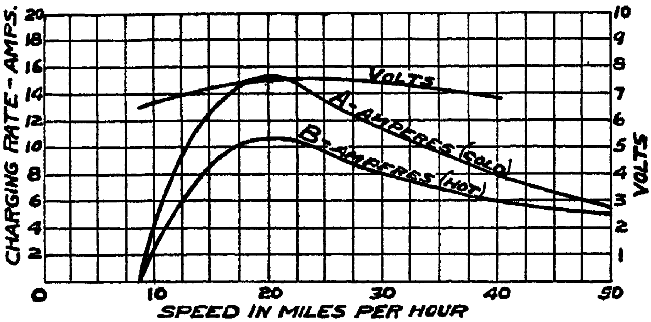


FIG. 548 —Curves illustrating charging characteristics of typical 3d-brush type generator. (*A*) Generator cold. (*B*) Generator hot.

type. Consequently, the same precautions are recommended in keeping the battery terminals clean and tight.

To operate the car with the battery disconnected, care should be taken that the generator does not build up a voltage. This may be done either by grounding the main generator terminal, shorting the main brushes, or by removing the shunt-field fuse if one is provided.

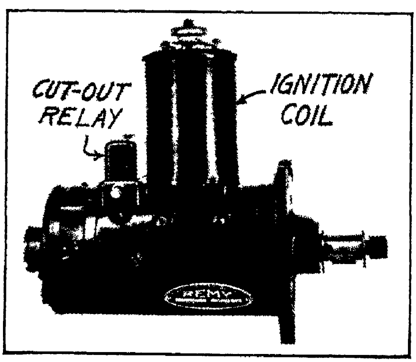


FIG 549 —Remy generator—Model 217-F.

374. The Remy Generator with Thermostatic Control.—The Remy generator, Fig. 549, is a 6-volt, two-pole generator in which the regulation is by the third-brush principle, supplemented by a thermostat mounted in the generator housing. The cutout

is mounted on top of the generator frame, and, in some cases, on the brush cap. The thermostat, Fig. 550, is composed of a resistance unit, two silver contact points, and a spring blade, at one end of which is mounted one of the contact points. The blade is made of a strip of spring brass welded to a strip of

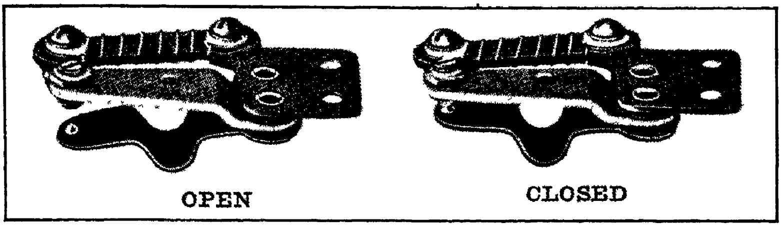


FIG. 550—Remy generator thermostat.

nickel steel, a combination which warps at its free end, when heated, due to the greater expansion of the brass side. The spring tension is fixed so that it holds the two contacts firmly together at low temperatures. As soon, however, as the temperature rises to approximately 160 to 165 deg F., the blade bends

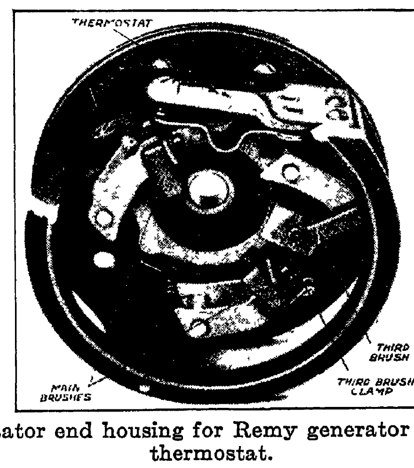


FIG. 551—Commutator end housing for Remy generator showing brushes and thermostat.

and separates the contacts. The thermostat is mounted above the commutator, on the same plate with the brush rigging, as shown in Fig. 551. It is connected in the shunt-field circuit, as shown in Fig. 552, so that, when the thermostat contacts are closed, full field current passes through them, permitting full cur-

rent from the generator. After the engine has been run long enough for the normally high charging rate to heat up the generator and the battery, the thermostat points open, due to the bending of the

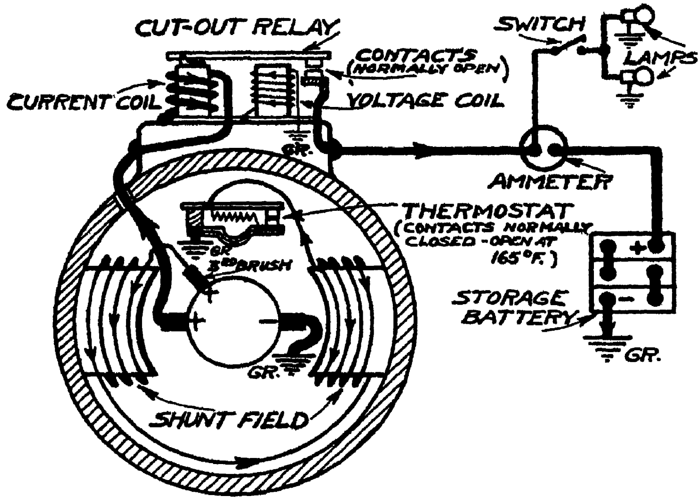


FIG 552.—Circuit diagram of Remy generator with 3d brush regulation and thermostat temperature control.

thermostat blade, causing the resistance to be inserted in the shunt-field circuit, and reducing the current output. The cold and hot generator current outputs, with the contacts closed and

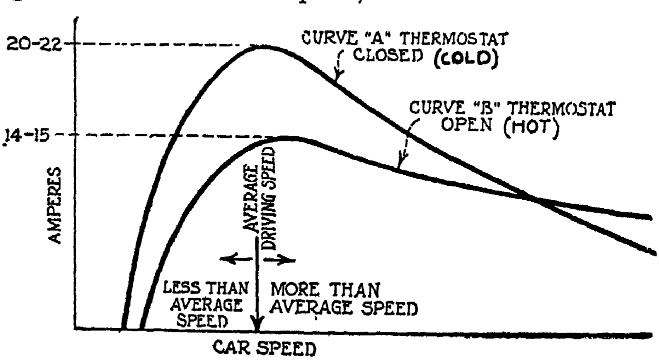


FIG. 553.—Curves showing relative charging rates of Remy generator with thermostat closed and open.

open, are illustrated by the two curves in Fig. 553, from which it will be seen that the charging rate reduces approximately 30 per cent when the thermostat is opened.

The chief advantages of thermostatic control are that it gives a large battery-charging rate in cold weather, when the efficiency of the battery is lower than in warm weather, and also a larger charging rate when the car is being driven intermittently and the demands on the battery are greater because of frequent use of the starting motor. It also prevents the generator and the battery from over-heating in the summer by the reduction of the charging rate when the temperature rises and the thermostat opens.

SECTION XXIII

STARTING MOTORS AND STARTER GENERATORS

375. Starting-motor Construction.—The general construction of the starting motor is similar in many respects to that of the generator. The principal parts, as shown in Fig. 554, consist of the field frame and windings, the armature, the brushes and brush rigging, the end housings and the drive mechanism. As explained in Sec. XIX, the method of drive may be through the Bendix drive, the silent chain, or the sliding pinion. The

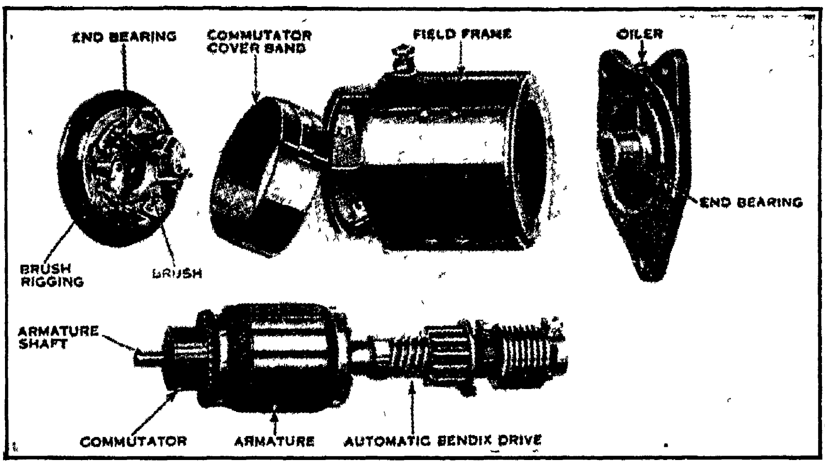


FIG 554 —Parts of typical starting motor (*Remy*)

Bendix drive, however, is the universal method, since it is automatic and does not depend upon the skill of the operator.

Because the starting motor runs only during the cranking period, the wear and tear on the unit is little, compared to that on the generator and, therefore, requires little attention. The bearings are usually of the bronze-bushing type, although in some instances ball or roller bearings may be found.

Several types of starting motors are shown in Fig. 555. The starting motor is usually mounted to the engine either by flanges which bolt to the flywheel housing, as shown in *A* and *B*, or by

the barrel-type mounting, as shown in *C* and *E*. Of the many types of starting motors which have been used, the round-type four-pole construction using a series-field winding has become the most popular. The operation of the motor is controlled usually by a foot-type starting switch located in the floor board.

The construction of the starting motor may vary considerably, due to the individual engine requirements and to the gear ratio desired between the armature and the engine crankshaft. Figure 556*A* shows the sectional view of a typical starting motor employ-

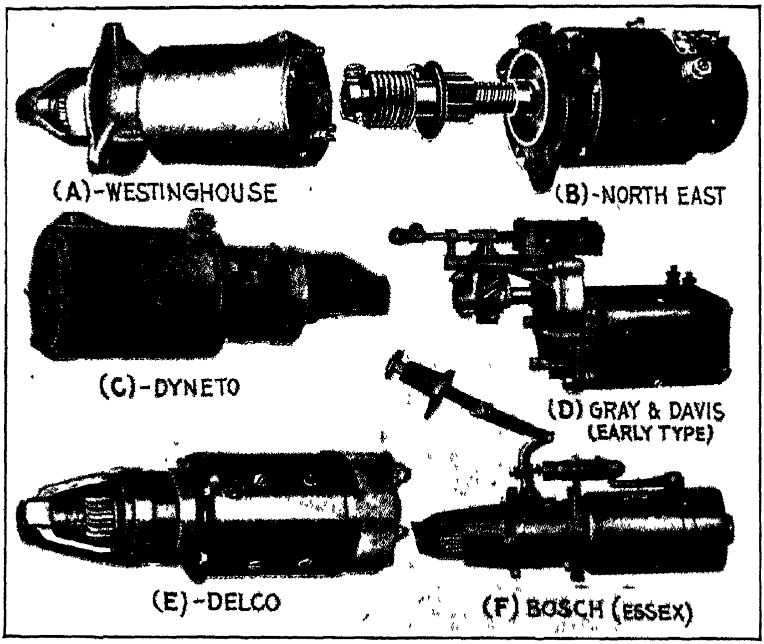
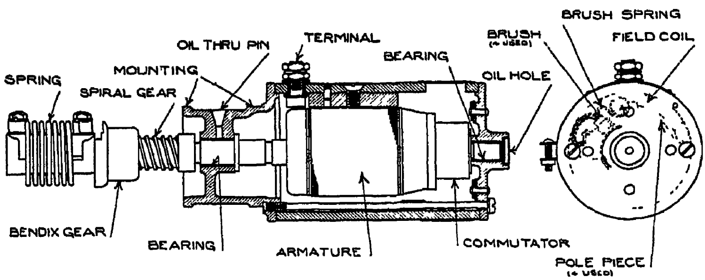


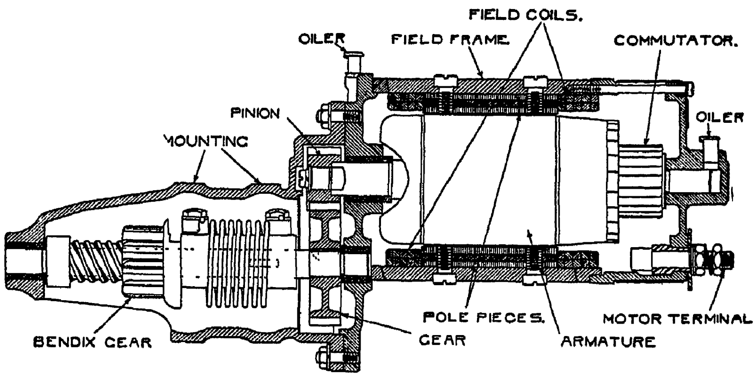
FIG. 555.—Types of starting motors.

ing single-gear reduction, in which the Bendix drive pinion meshes directly with the teeth on the flywheel, while Fig. 556*B* shows a typical starting motor in which double-gear reduction is used. With the usual single-gear reduction, such as shown in Fig. 556*A*, the gear ratio between the armature shaft and the crankshaft may be 12 to 1, 11 to 1, or 10 to 1, depending upon the size of the pinion used. Thus, if the engine is to be cranked at, say, 100 r.p.m., the starting-motor armature speed must be 1,000 to 1,200 r.p.m., depending upon the gear ratio. In fact,

the higher the gear ratio the higher the armature speed will be, and the smaller the motor as a whole can be. Therefore, the double-reduction drive is sometimes used to reduce the size and the weight of the starting motor, and to obtain higher motor efficiency, because the armature runs at a higher rate of speed than in the single-reduction type of starting motor.



(A)



(B)

Fig. 556.—(A) A sectional view of typical starting motor with Bendix drive—inboard type—for barrel mounting (Delco). (B) Sectional view of Delco starting motor with Bendix drive and reduction gears—outboard type.

The average starting motor is designed to deliver ½ to 1 hp, the average current consumption during the cranking period being 125 to 175 amp. on a 6-volt battery. At the moment the starting switch is closed, however, it may draw twice this amount, the current decreasing in value as the engine is accelerated to the full cranking speed. Thus, all current-carrying members, such as starting switch, cables, brushes, field coils, armature coils, etc., must be liberally proportioned in order to handle the heavy current without undue resistance and heating. The battery must also be capable of high discharge rates.

376. Operation of the Starting Motor.—The fundamental principles of the simple D.C. electric motor were explained in Art. 40. The circuits of a typical two-pole starting motor are shown in Fig. 557*A*. The field magnetism is produced by a series-field winding through which all the current which passes through the armature must flow. Although the series winding is composed of only a few turns of heavy wire, a strong field is produced due to the high current, and a high-cranking power or *torque* is obtained.

Instead of having one armature coil acting alone to cause rotation, as in Fig. 557, there are, in reality, several armature coils acting as a unit to give the armature rotation. From

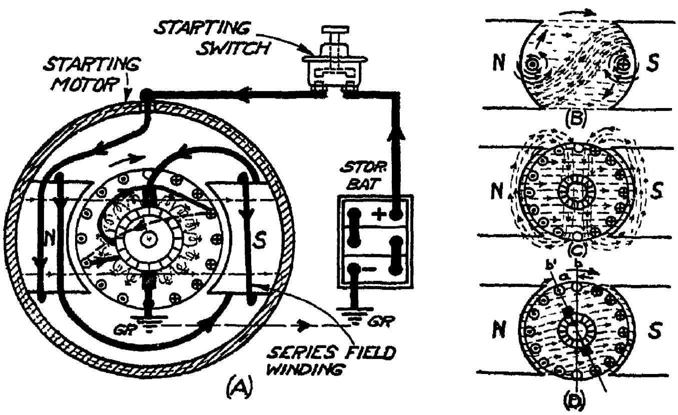


FIG. 557.—Circuits and operation of 2-pole starting motor.

a study of Fig 557*A* it will be seen further that the function of the commutator is just the reverse of that in the D.C. generator, namely, to convert the direct current from the battery into alternating current within the various armature coils in order to keep the current passing through them in the proper direction so as to cause rotation in one direction only.

377. Relation between Direction of Magnetism, Current, and Motor-armature Rotation.—The relative direction of the repulsion of a conductor with respect to the direction of current and magnetism is shown in Fig. 558. A convenient rule for determining this relation, known as the "left-hand rule for motors," is shown in Fig. 559. The three fingers of the left hand are simply held at right angles to each other as shown, the thumb pointing

in the direction of magnetism, and the front or index finger in the direction of current in the armature coil. The second finger will naturally point in the direction of motion. Thus, if two of the three factors are known, such as the current and rotation, the current and magnetism, or the rotation and magnetism, the third unknown factor can readily be determined by holding the fingers as shown.

Note—This rule should not be confused with the right-hand three-fingered rule for generators described in Art. 37, page 34.

Referring to Fig. 557*B*, which illustrates one armature coil taken from the armature shown in Fig. 557*A*, the magnetic field that is set up around the conductor, due to current flowing in it, will

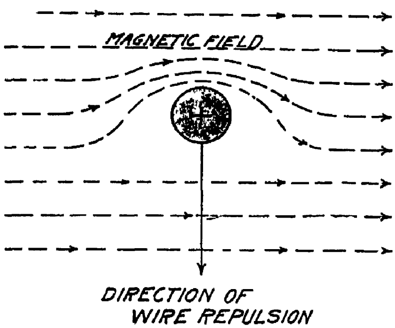


FIG. 558.—Relation between direction of magnetism current and repulsion of conductor.

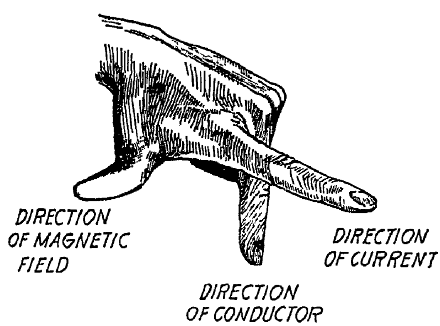


FIG. 559.—Left hand rule for motors.

cause a reaction with the main magnetic field, as shown The result is that the side of the loop next to the north pole will be repulsed upward, while the side next to the south pole will be repulsed downward, thus causing a rotation clockwise, as indicated by the arrow. The same action takes place in all of the armature coils which come within the range of the main magnetic field.

Field Distortion.—Because of the cross-magnetism set up in the armature core due to the current flowing in the armature coils, as illustrated in Fig. 557*C*, a reaction will be set up between the two fields which will cause a general distortion of the main magnetic field through the armature as shown in Fig. 557*D*. From this, it will be noted that the field distortion is in the opposite direction to the direction of armature rotation, with the result that the

brushes must be shifted slightly in the direction of field distortion, or opposite to the direction of armature rotation, in order to be in the best running position. This is just the opposite to that of the generator (see Art. 357), where the brushes must be shifted slightly in the direction of armature rotation to compensate for field distortion.

To Reverse Armature Rotation.—Should the current be reversed through the starting motor, Fig. 557*A*, it might be expected that this would reverse the direction of armature rotation. This is not the case, however, since, being a series-wound motor, the field magnetism and the armature current will both reverse, producing the reactions shown in Fig. 560 and causing the direction of rotation to be the same. However, should the direction of either the armature current, as in *B*, or the field magnetism, as in *C*, be reversed—but not both—then the field distortion will be in the opposite

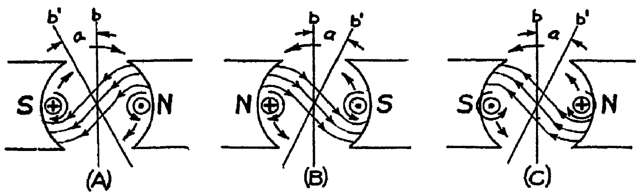


FIG 560.—Showing effect of magnetic polarity and armature current on armature rotation and field distortion—*b* indicates neutral brush line and *b'* the best position due to distortion

direction and the rotation will be reversed as shown. In practice, the reversal of armature rotation may be accomplished either by reversing the leads to the brushes, or, as in the case of round-type four-pole starting motors, by turning the end housing and brush rigging one-fourth turn from its proper position. This reverses the brush positions and produces the same effect as reversing the brush leads.

378. Circuits of Typical Starting Motors.—Although practically all starting motors are of the series-wound type, the method of connecting the field coils with respect to the brushes and the armature may vary considerably. Typical automobile starting-motor circuits are shown in Fig. 561. *A* and *B* show typical two-pole types, while *C* to *H* and *I* show four- and six-pole types respectively. As will be noted, the principal differences lie in the connecting of the field coils. In *B*, *C*, *D*, and *F* the coils are in series with each other and the armature, while in *E*, *G*, and *H* they are in parallel groups which are in series with the armature. The advantage of this construction is a reduction of the resistance of the starting-motor circuit.

An unusual method of winding the field is shown in Fig. 561*I*, which illustrates the Dyneto six-pole starting motor used on the 1924 Packard Eight. Instead of winding the coils completely around the pole pieces, as is usual practice, the insulated copper strips which form the field are simply wound in and out between the poles, as shown in the small diagram at the right. The result, however, is the same.

Where only two brushes are shown with a four- or a six-pole armature, as in *C* and *I*, it is evident that the armature is of the wave-wound type. Where all the brushes are used, however, the armature may be either of the lap- or of the wave-wound construction.

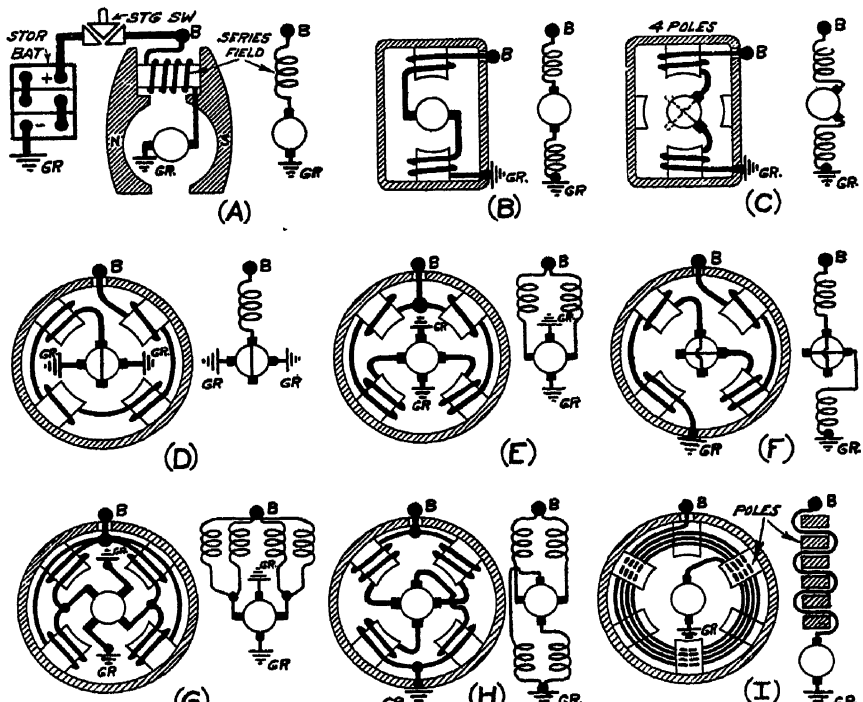


FIG. 561.—Circuits of typical starting motors.

379. Starting Switches.—The function of the starting switch is to provide a means of closing the starting circuit during the cranking period, and for its remaining open to prevent current discharge at all other times when the starter is inoperative. Figure 562 shows typical plain foot-type starting switches, while Fig. 563 shows the Westinghouse electromagnetically operated type, in which the starting motor is operated by the pressing of a button on the dash.

The usual starting switch requires very little attention other than an occasional inspection to make sure that the terminals

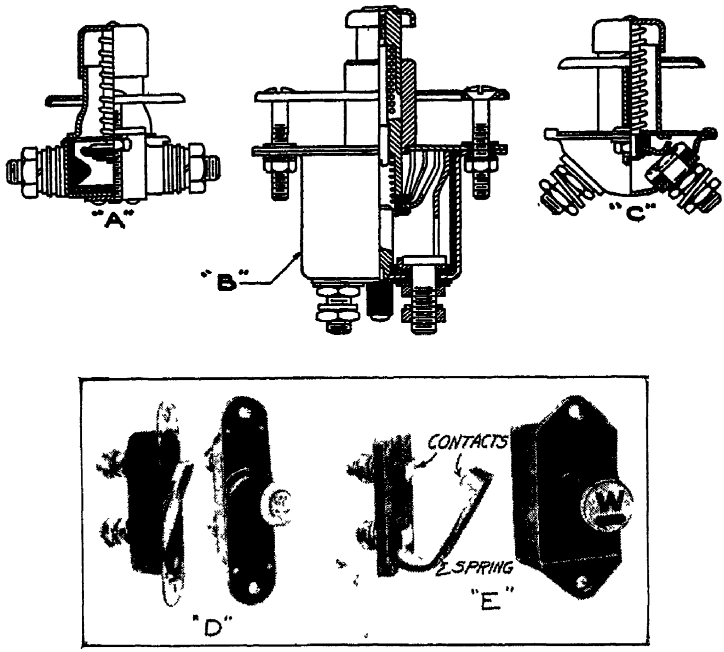


Fig. 562.—Types of starting switches—foot operated types. Upper shows Delco types; lower, Westinghouse types.

are kept clean and tight. It is also important that, when the switch is depressed, plenty of pressure be applied to insure good

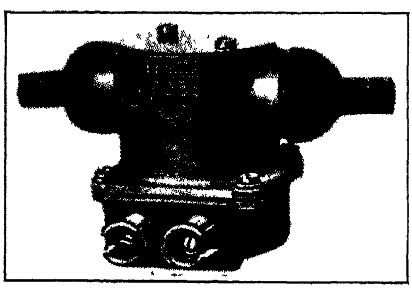


Fig. 563.—Westinghouse electromagnetically operated starting switch.

switch contact; also that, when the switch is allowed to open after cranking, the contacts are opened quickly to prevent arcing, burning, and sticking.

380. Principles of the Starter-generator.—The *starter-generator*, sometimes referred to as a *dynamotor*, is merely a single-unit dynamo which is designed to function both as a generator for charging the battery, and as a starting motor for cranking the engine. In its simplest form the same windings and brushes function when it is used both as a motor and as a generator. In other designs the motor and generator windings are separate, the armature being double-wound and provided with two commutators and sets of brushes. In reality, this design provides two machines in one—one being disconnected electrically while the other is operating. An example of this type of construction is found in the Delco single-unit system described in Art. 410. Although the cranking and generating are performed by a single-unit machine, it is not usually termed a starter-generator in the true sense of the word.

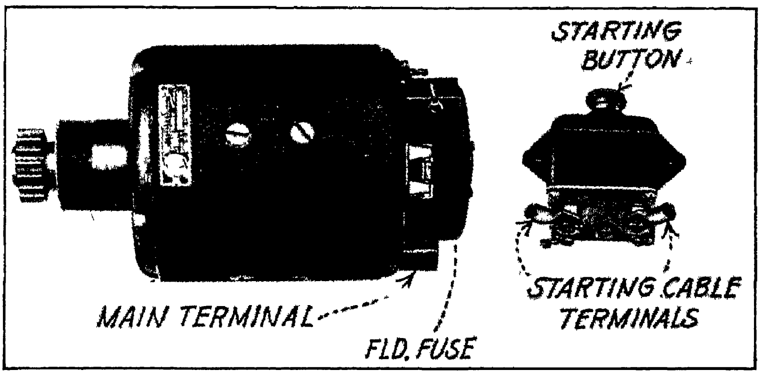


FIG. 564.—North East starter-generator, Model G, and starting switch-cutout unit, type 8100-A, as used on Dodge car.

A typical example of the starter-generator is found in the 12-volt North East unit, Model G, Fig. 564, which has been used extensively on the Dodge car. Circuits of the starter-generator unit, including cutout, are shown in Fig. 565. The starting and generating characteristics are shown in Figs. 566*A* and *B* respectively.

As will be noted in Fig. 565, the field contains two windings, a shunt and a series, the shunt winding being connected between a third brush and the upper main brush which is grounded through the series winding, while the series winding is split in two sections, both of which are connected in series with the armature and the battery. When the unit operates as a generator, it will be noted that the two windings operate differentially, *i.e.*, the series winding produces magnetism to oppose the shunt winding, so as to

bring about current regulation. This is in addition to regulation produced by the third-brush method.

When the starting switch is closed, causing the battery to discharge through the starter-generator operating it as a motor, the two windings will be found to operate accumulative, *i.e.*, the series winding assists the shunt winding so as to produce a strong magnetic field and a high-cranking torque. After the engine has started and runs under its own power at a speed where the

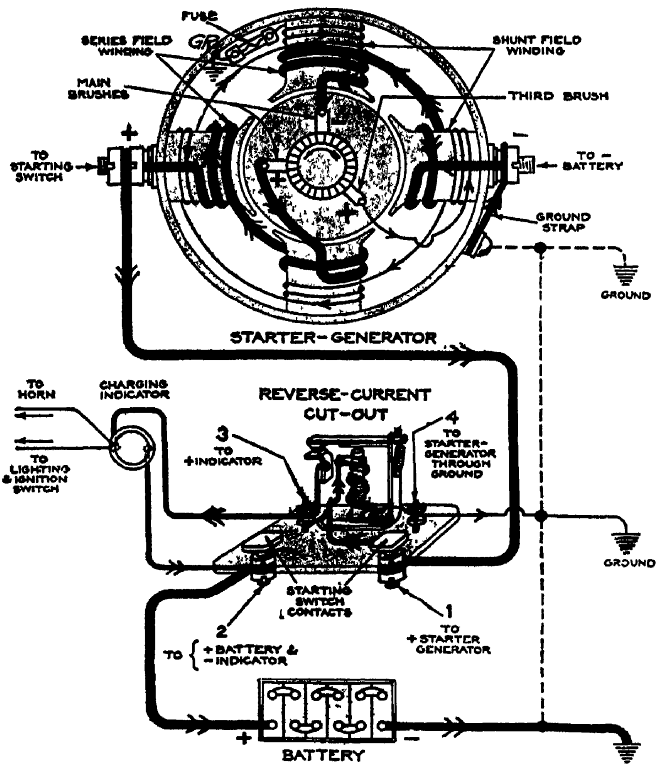


FIG. 565.—Circuit diagram of North East starter generator, Model G, and cut-out.

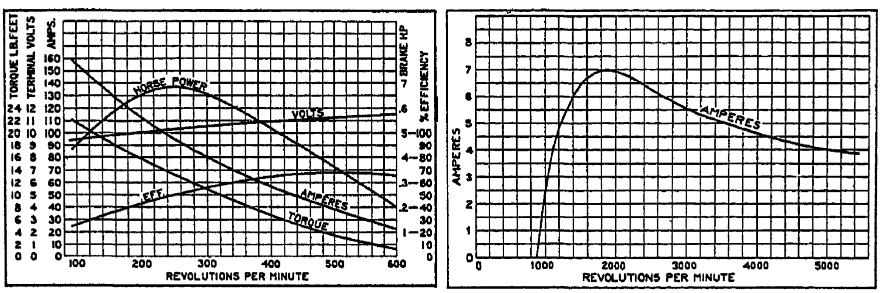
armature is driven faster than it would normally rotate as a motor, the armature windings, due to cutting of the magnetic lines of force, will generate a voltage which will increase as the speed increases. When the voltage of the generator becomes greater than the countervoltage set up by the battery, the current reverses in the main circuit, and flows through the battery in a charging direction.

For this model of starter-generator, the charging rate should be approximately 7 to 8 amp. at 20 to 25 m.p.h., after which speeds the rate should diminish due to the characteristics of third-brush regulation. As a starting

motor the maximum horsepower delivered, Fig. 566*A*, is 0.68 hp., which is obtained at a rotative speed of 250 r.p.m. At this speed, the motor draws approximately 70 amp. of current at 7 volts. The gear ratio is 2½ to 1, the drive being through a silent chain from the front end of the crankshaft.

381. Horsepower Requirements of Starting Motors.—The actual horsepower which a starting motor must develop in order to crank an automobile engine at a definite speed varies considerably with the conditions under which it operates. The most important factors which govern its performance are as follows:

1. The number of cylinders and the cylinder bore.
2. Compression pressure.
3. Cranking speed desired.
4. Temperature and characteristics of the lubricating oil.
5. Friction in the engine and in the starting motor.
6. Gear ratio between armature and crankshaft.
7. Efficiency of the starting-motor drive.



(*A*) As starter, (*B*) As generator

FIG. 566.—Curves showing starting and generating characteristics of North East, Model G, 12-volt starter-generator.

In general, it may be said that the required horsepower varies from one-half to three-fourths for engines of medium size, as used in passenger cars. The most severe service which the starter must render is, of course, in cold weather when the engine is stiff, and when the storage-battery efficiency is low and carburetion is difficult. Thus, if the starting motor and battery are capable of obtaining proper cranking speed in cold weather, it is sufficient to assume that they will have proper cranking power or *torque* during the summer months. As a matter of fact, the torque needed to crank in cold weather may often be taken as about

three times the torque required under ordinary conditions, say, around 70 deg. F. Furthermore, if it is desired to provide for extreme cold, an assumption that the torque will be four times as great is usually not far from correct.

382. Methods of Testing Starting Motor for Cranking Power. The cranking power of a starting motor is determined by its ability to rotate under load, that is, to produce a torque. It may be measured by clamping the starting motor in a vise and noting the pounds' pull which will be exerted at the end of a

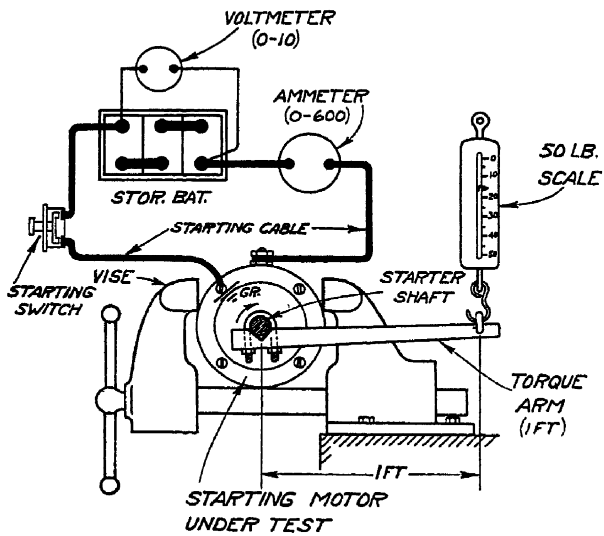


FIG. 567—Method of testing starting motor for lock torque and maximum current draw.

1-ft. arm clamped to the starting-motor shaft as shown in Fig. 567. Two factors may be determined: (1) the maximum current which the motor will draw when "stalled" and (2) the lock torque, or the rotative force, which is sufficient to prevent the armature from rotating when the starting switch is closed. The torque is measured in pounds-feet, that is, the number of pounds exerted on the scale multiplied by the length of the torque arm in feet. If the torque arm, however, is 1 ft. in length as mentioned, the torque in pounds-feet will correspond to the reading of the scales minus the weight of the torque arm when the armature is not under load.

By connecting an ammeter of suitable range, say, 0 to 600 amp., and a voltmeter, say, 0 to 10-volt range, as shown, the input in watts may be determined at the time the torque is measured. The extent of the current draw may be used to determine the electrical condition of the motor and the storage battery, while the lock torque may be used to determine the ability of the starting motor to "break the engine loose" and to start it rotating. Furthermore, should the ammeter show unusual high-current values, yet the lock torque is below the normal value, it is an indication that the internal motor windings are defective—possibly "short-circuited" or "grounded"—thus preventing it from producing the proper torque; or it may be that the armature is dragging on the pole pieces, due to defective bearings or a bent shaft. On the other hand, should both the current draw and the lock torque test below normal, yet the battery maintains its proper voltage of, say, 3 to 4 volts or over, it is an indication of excessive resistance in the starting circuit. This may be due to (1) corroded terminals, (2) poor starting-switch contact, (3) loose or dirty cable connections, (4) starting cables too small or too long, (5) oily or dirty commutator, (6) brushes or brush leads of insufficient capacity, (7) brush leads disconnected from brushes, (8) insufficient brush-spring tension, (9) brushes sticking in holder or not seating properly, (10) open-circuited armature coils, and (11) improper ground connection, due to oil, rust, or paint.

383. Operating Characteristics of Typical Starting Motors.—Curves showing the various operating characteristics of a typical 6-volt starting motor as to horsepower, torque, efficiency, etc. are shown in Fig. 568. These curves represent a typical Westinghouse starting motor for medium-sized automobile engines and may be considered typical for two-unit 6-volt systems. The curves shown in Fig. 566 may be considered typical for 12-volt starter-generators operating under normal conditions.

It will be noted by referring to Fig. 568 that the maximum horsepower of 0.86 is obtained with approximately 200 amp. flowing at 5 volts. The greatest efficiency, however, which is denoted by the highest point in the "efficiency" curve, is obtained with 150 amp. at 5.3 volts. And, by following down the vertical line to the "speed" and "torque" curves, this line will be found

to cross these curves at their intersection, a point which represents a speed of approximately 1,500 r.p.m. and a running torque of 3 lb.-ft. The maximum efficiency is about 75 per cent.

The operating characteristics of several typical starting motors of different makes, as used on different types and sizes of automobile passenger-car engines, are given in the following table. The information given in this table will be found helpful in making comparative performance tests of the different types of starters as to *running free*, *cranking engine*, and *lock torque*

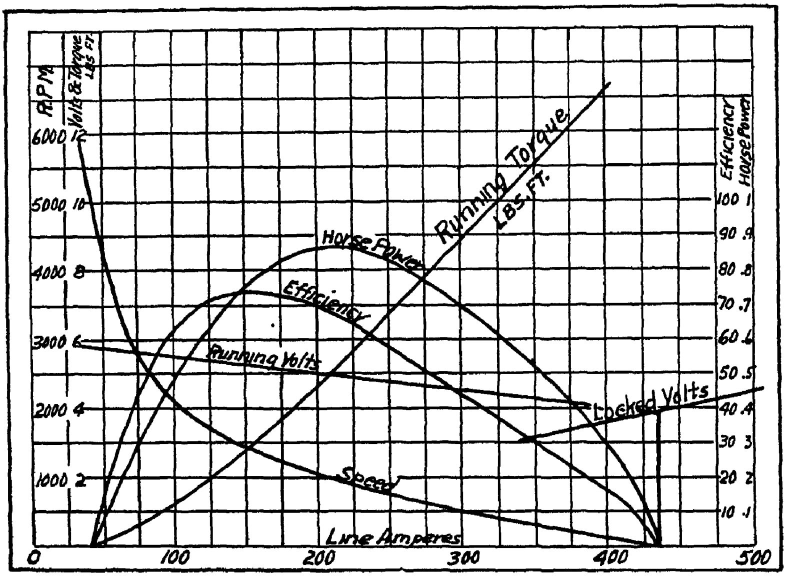


FIG. 568.—Curves showing characteristics of typical Westinghouse 6-volt starting motor.

when operating under similar conditions. It is important that a fully charged battery of the type specified—and operated at normal temperature—be used.

Through a study of this table it will be noted that, when running free, the average 6-volt starting motor draws 40 to 60 amp. and attains a speed of about 4,000 r.p.m., but, when cranking the engine at the normal cranking speed of about 125 r.p.m., the average current draw is approximately 150 amp. at 5 volts. Furthermore, the "stall" current is approximately 400 amp. at 3 to 4 volts and the torque is 10 to 16 lb.-ft. where single-reduction gear ratio is used.

Operating Characteristics of Typical Starting Motors

Starter	Model No.	Engine: Make and model	Engine: Cycles	Engine: Rated horsepower	Regular storage battery: Make	Regular storage battery: Type	Regular storage battery: Volts and ampere-hour	Running free: Amperes	Running free: Volts	Running free: R p m.	Cranking engine: Amperes	Cranking engine: Volts	Cranking engine: R.p m.	Lock torque: Amperes	Lock torque: Volts	Lock torque: Torque in pound-feet
Atwater-Kent ..	6484	Packard S6	6	27 34	Willard	SJWN4	6–100			.	125–175	5	150	450	3–4	14
Auto-Lite. . . .	GH	Durant	4	24 03	U. S. L.		6–92	40	6	4,000	120–160	5 5	110	400–450	4	10
Bijur.	M–800, M–1041	Packard-"Twin Six"	12	43 2	Willard	SMR7	6–134	60	5 8	6,800	175–225	5	120	550	3 6	16 5
Bosch (American)	900	Cleveland 42	6	22 5	Prestolite	611RHN	6–80	35–40	6	..	150	5	110–150	400	3–4	15
Delco.	251	Buick 33-45-7	4	18 3	Exide	3XC151	6–100	70	6	4,000	125–175	5	125	400	3 0	6
Delco.	208	Jordan MX	6	26 34	Willard	SJR-4	6–111	40	6	4,000	150–175	5	125	500	2 75	27
Delco.	98	Cadillac V-63	8	31 25	Exide	3LXRV–15-2	6–130	70	5 5	4,000	150–250	5	125	450	3 0	6
Dyneto	K-I-R	Franklin 9B	6	25 35	Willard	SJW26	12–49	10	12	600–800	50–70	11	100–150	210	9	30–40
Ford.	Own	Ford T	4	22 5	Exide	3XC13	6–84	70	5 5	4,000	150–160	5	150	450	3–4	12
Gray & Davis.	532	Lexington 23	6	25 35	Willard	SJR4	6–111	45	6	4,500	150	5–5½	100–200	500	3 5	15
Leece-Neville . .	388-M	Haynes 55	6	29 4	Willard	SJR4	6–111	60	6	...	125–200	5	125	600	3 4	16
North-East . .	3804	Dodge 1924	4	24 03	Willard	SJR26	12–49	..	...	. .	80	11	300	180	8 9	31
North-East	3581A	Reo T6	6	24 34	Willard	SJRN4	6–111	40–60	5½	4,000	125–150	5–5½	125	470	3 5	10
Remy	723B	Oakland 6-54	6	18 99	Prestolite	613RHN	6–100	65	5	5,000	.....	.	.	475	3 6	12
Simms-Huff . .	SMS-3	Maxwell 25 (19–1920)	4	21 03	Prestolite	127WHN	12–38	5	13	1,100	50	11–12	150	200–275	10–11	16
Wagner .. .	EM201	Studebaker L6	6	23 44	Willard	SJRN3	6–90	60–90	6	8,000	160	5 5	110	475	3–4	35
Westinghouse .	33AB	Gardner 4	6	21 76	Willard	SJR–3	6–94	35–45	5 5	4,100	150–200	5–5 5	100–150	450	4	12

To obtain the best efficiency and performance from any starting motor in service, it is important that the brushes be of proper quality and make perfect contact with the commutator; that the bearings are properly adjusted and oiled; that the driving pinion meshes properly with the starting gear; and that the starting battery is of proper type and in good condition; and that all connections are clean, tight, and of proper current capacity. It is also assumed that the engine turns freely when cranked.

SECTION XXIV

BRUSHES AND BRUSH RIGGING

384. Dynamo Brushes.—The function of the brushes is to conduct the current to and from the armature by a rubbing contact with the commutator bars. On the early types of generators and motors, long before the days of the automobile, the brushes originally employed were strips of copper which bore on the commutator. As the generators and the motors increased in size, these brushes were built up of thin strips of copper, but results showed that plain copper brushes in any form caused an excessive amount of sparking, which was ruinous to the smooth surface and the true running of the commutator. They also caused excessive wear and involved the problem of lubrication.

The built-up copper-gauze brushes were next to be tried and, while they were an improvement, did not meet all the requirements, and so were superseded by carbon and metal-graphite brushes. The great difference in the performance of the starting motor and the automobile generator called for a marked difference in the composition of the brush to be used on each.

385. Brush Requirements.—On account of the limitations of space in the automobile and the necessity for minimum weight, the motor and the generator are consequently small. This means that the commutators, the brushes, and the brush holders must also be comparatively small. Because a low voltage is used on the starting motor the current must be high. This puts a great stress on the commutator and a greater stress on the brushes. Because of this high-current requirement of the starting motor, it has been necessary to design a brush of especially high-current capacity. For this purpose the metal-graphite brush has been produced. Generally speaking, metal-graphite brushes consist of various mixtures of pulverized copper and graphite.

For the generator, which it must be remembered operates continuously with the automobile engine, a brush must be used which

has a long life, self-lubricating qualities, and little or no abrasive properties, that is, the friction with the commutator is reduced to a minimum. With the generator brush, reliability is the important factor and it has been found that a special graphite brush answers the requirements very nicely. The same brush, however, would not give satisfaction in a starting motor, nor would a starting-motor brush be satisfactory in generator service.

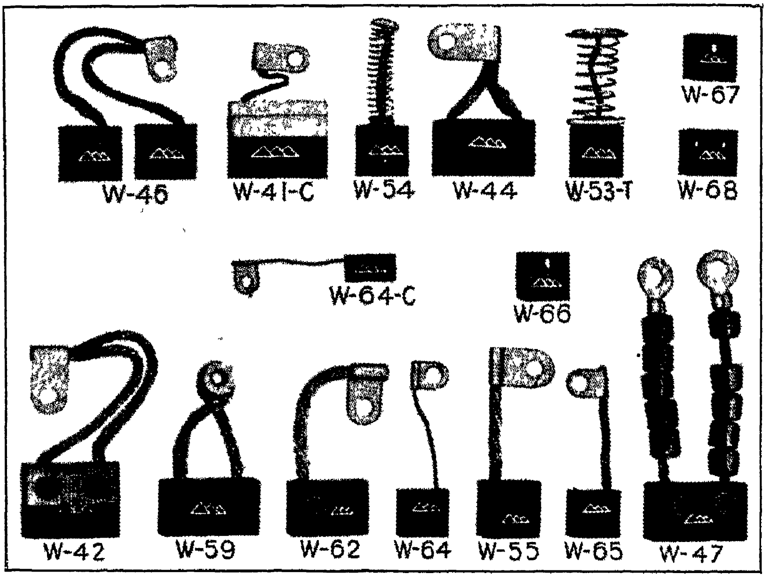


FIG 569—Types of brushes used in Westinghouse starting and generating equipment.

386. Types of Brushes.—There are four types of brushes commonly used on all popular and well-known systems: (1) 6-volt generator brushes, (2) field or control brushes which are the same for both 6- and 12-volt generators, (3) 12-volt starter-generator brushes, (4) 6-volt starting-motor brushes. In Fig. 569 is shown an assortment of typical brushes used.

387. The Generator Brush.—The function of the generator is, of course, to keep the storage battery charged. Where a car is in normal use, a charging rate of about 12- to 14-amp. is required to keep the battery in condition on a 6-volt system. One of the fundamental rules applying to most types of generators is that the material of which the brush is made must have high enough

contact resistance to overcome the short-circuit current between two or more commutator bars which may be in contact with the brush, so as to reduce sparking, as illustrated in Fig. 570. This means that the brush must be made of carbon, or a combination of carbon and graphite, to meet these requirements. Furthermore, the material must be abrasive enough to keep the commutator clear of oil, grease, or dirt, and at the same time keep the mica worn flush with the commutator bars where unslotted commutators are used.

Another function of the abrasive-type brush is to prevent the commutator from becoming coated with carbon deposit because of frequent sparking under the field-control brush. Scouring with a slight abrasive brush will prevent this condition.

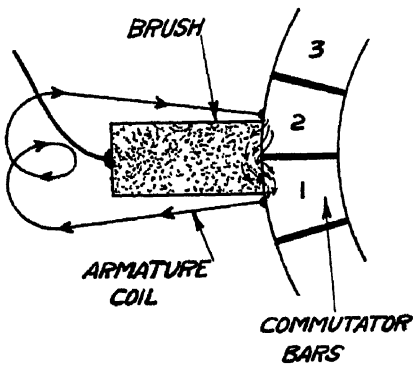


Fig. 570.

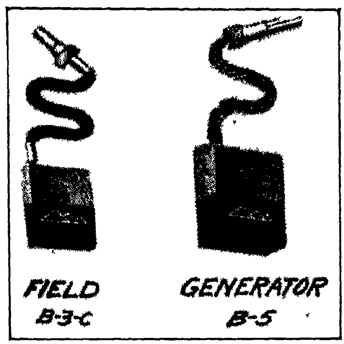


Fig. 571

Fig. 570.—Showing how a brush momentarily short-circuits each individual armature coil, causing sparking, when the brush is not located in the neutral plane The arrows indicate path of current through the coil and brush.

Fig. 571.—Field control and generator main brushes for Bijur gnerator, showing relative sizes.

Since the generator brush is continually in use while the engine is running, and because the generator is running at a relatively high speed a good portion of the time, some satisfactory method of lubrication must be provided. This can be secured by having sufficient graphite in the brush material to furnish satisfactory self-lubrication. Also, the generator brush must have sufficient carrying capacity to conduct the normal current without undue heating. At the same time, allowance must be made for outside heating due to friction between the brush and the commutator and the heat conducted to it from the engine and from the armature windings. The brush used must also have a fairly high factor of safety, that is, it should be capable of withstanding much more than is actually expected of it.

388. The Field-control or Third Brush.—The generator field-control brush (or third brush) is very important, since it controls the output of the generator and, consequently, the load carried by the other main brushes. The carrying capacity of this brush need not be as high as that of the main brushes, inasmuch as the amperage at this point is lower, and consequently the current density, that is, the current flowing per square inch, will be lower. The contact resistance of this brush is important, however, because it is placed at a point on the commutator where the bar-to-bar voltage is high. Consequently, if this brush does not have high enough resistance, severe sparking will occur. Also, the brush must not be too thick, as this would also cause excessive sparking. This accounts for most of the field-control brushes being thinner than their respective main brush, as shown in Fig. 571.

389. Starter-generator Brushes.—The brush requirements of the starter-generator are more complex than those for the generator. It is necessary to use a brush with a greater percentage of metal than in the average generator brush, in order to have sufficient carrying capacity for the heavy work required in cranking when the unit is running as a motor, and in order that the contact resistance may be low enough to produce the required torque. On the other hand, when the unit is running as a generator at the high speeds imposed upon it, there must be sufficient graphite in the brush to furnish satisfactory lubrication, and the contact resistance must be high enough to overcome the short-circuit current between two or more commutator bars, as shown in Fig. 570. Service of this kind requires a combination of carbon and graphite in such proportion and blend as to produce a fairly hard brush of fairly high-carrying capacity and medium contact resistance.

390. Starting-motor Brushes.—In starting-motor service, the principal demand of the brush is that it give the lowest possible contact resistance and permit the highest consequent torque with good commutation. Brushes of wire gauze pressed into rectangular form are used on some makes of starting motors, but where such a brush is used the commutation of the motor must be necessarily good, or the brushes will fray out at the face and excessive sparking and commutator wear will occur.

During the entire life of the car the total actual service of a starting motor is probably not more than a few days and therefore the brush life is of less importance than on the generator or starter generator. In fact, the question of brush life on the starting motor is almost entirely one of good commutation. The starting-motor brushes must be high in metal content, in order to carry the amperage necessary to give the required torque. At the same time the ideal motor brush should have a small per cent of graphite, to furnish self-lubrication, and a small per cent of ash content, to serve as an abrasive to keep down high mica where unslotted commutators are used and also to keep the commutator free from oil, grease, and other foreign matters.

391. Brush Characteristics.—The characteristics of brushes used in generators and motors may be classified as mechanical and electrical. The mechanical characteristics are: (1) dimensions, including size, length, width, and thickness; (2) coefficient of friction; (3) hardness; (4) strength; (5) abrasiveness; and (6) density.

The electrical characteristics include: (1) specific resistance; (2) contact resistance; (3) variation in specific resistance and contact resistance with heating, and (4) carrying capacity. Both the mechanical and the electrical characteristics of brushes will vary with the composition, which, in turn, may vary considerably. The classification according to composition is as follows: (1) pure carbon brushes; (2) carbon and graphite brushes, which, in turn, may be composed of (*a*) mixtures of carbon and artificial graphite, and (*b*) mixtures of carbon and natural graphite; (3) electrographitic brushes, in which the graphite properties are brought about by special electrical treatment; (4) pure natural or artificial graphite brushes; and (5) metal-graphite composition brushes.

392. Mechanical Characteristics of Brushes.—There are no general rules to determine the size or the shape of automobile-generator or starting-motor brushes. The width and the thickness of the brush must be such that the current density is near normal for the brush material to give satisfactory commutation. Furthermore, for automotive service, it is necessary that the brush be thick enough so that it will be in contact with at least two commutator bars at all times. The various shapes and sizes of starting and lighting brushes now in use, examples of which were shown in Fig. 569, can be attributed to the many special types of brush holders, the individual design of the units, and the methods of brush attachment.

The coefficient of friction enters into the consideration of brushes for large industrial motors and generators and is seldom considered in automotive electrical service. In general, however, a brush with a high coefficient of friction should not be used on commutators which run at extremely high speeds, due to the loss of power and heat generated.

Brush Hardness.—In carbon, graphite, and carbon-graphite brushes, hardness is usually indicative of strength. A hard brush is usually the strongest, but has a greater tendency to chip. The wearing qualities or life of a brush should not necessarily be confused with its degree of hardness. A soft brush applied to the service it was intended for often outwears a harder brush in the same service. Under normal conditions, the reliable generator brush will take on a polished, but not a glazed, surface, which not only provides good commutation but has a protective coating that minimizes the wear of both the brush and the commutator.

Abrasiveness.—The ash content of the brush material determines largely its abrasiveness. The amount of ash can be determined by heating the brush in a special furnace to a temperature which will burn out all the carbon. Silica, mica, and carborundum form the major part of the abrasive material found in the ash of carbon brushes. In a general way, abrasive brushes should be used where the mica between commutator bars is not undercut, where excessive voltage and sparking smudge the commutator with a non-conductive coating, or where foreign material, such as oil, grease, or dirt, collects on the commutator. Many mechanics and electricians have the impression that hard brushes are abrasive and soft brushes are not. This is not necessarily true, since hard brushes are now manufactured which are strictly non-abrasive, while some of the softer grades have pronounced abrasive characteristics.

Brush Density.—The density of a brush may be *real* or *apparent*. The real density is the weight of the material, exclusive of the pores, compared to the weight of an equal volume of water. The average real density of brushes is approximately 2.00. The apparent density is the weight of the material, with the pores, compared to the weight of an equal volume of water. The average apparent density of brushes is approximately 1.5. The average pore space in brushes amounts to 25 per cent. For high-speed service, such as in automobile generators, the low-density brush is particularly adapted, because of its low inertia, which enables it to follow more readily the irregularities of the rotating commutator.

393. Electrical Characteristics of Brushes.—The electrical characteristics of any brush depend largely upon its specific and its contact resistances, the variation of these resistances with temperature, and the carrying capacity of the brush material. The *specific resistance* is the resistance in ohms of a cube of the

brush material the sides of which are 1 in. long. It is obvious that, for automotive brushes, the specific resistance is dependent on the material of which they are made.

In calculating this specific resistance, or resistance per inch cube, the following formula is used:

$$R = \frac{K \times L}{W \times T} \tag{15}$$

in which R = total ohmic resistance of brush; K = specific resistance in ohms per inch cube; L = length of brush in inches; W = width of brush in inches; T = thickness of brush in inches.

It has been found that satisfactory automobile brushes have a specific resistance K as follows:

Generator, 0.0015 to 0.00055 ohms per inch cube.
Starter-generator, 0.00006 ohms per inch cube.
Starting motor, 0.000003 to 0.000021 ohms per inch cube.

The contact resistance of brushes is the resistance between the commutator and the brush when current is flowing This normally becomes less as the current density increases, but where the brushes are undersize the brushes will heat up and the contact resistance will be especially high, probably due to the oxidation of the surface of the commutator. It should be remembered that, in carbon the resistance decreases as the temperature increases. Therefore, as the brush heats up, the specific resistance decreases.

For practical purposes it is safe to assume that a change in temperature has no effect on contact resistance. Furthermore, the *contact drop* (which is the voltage drop across the contact between the brush and commutator) may also be considered approximately uniform, for all current densities within the range of normal operation. While the specific resistance of the brush has some effect on the commutation of a machine, this effect is not as marked as that caused by the contact resistance, since the latter has the desired opposition to short-circuit currents. Over wide ranges, the contact resistance and the contact drop increase as the specific resistance. The two work together in overcoming the short-circuit currents.

In general, the contact drop is less in the graphite than in the amorphus-carbon brush. This is relatively true of specific resistance.

From the above, it must be remembered that the contact resistance and, therefore, the contact drop, depend not only on the condition and character of the brush and the commutator, but also on the brush pressure.

394. Brush Pressure and Method of Testing.—From the foregoing, it is evident that brush pressure is an important factor in the successful operation of the brushes. For the usual type of 6-volt generator—for example, the Delco—the normal brush-

spring tension should be approximately $1\frac{1}{2}$ lb., while for the starting motor it should be from $2\frac{1}{2}$ to $2\frac{3}{4}$ lb. for the usual types. In most cases an accurate check of the brush-spring tension cannot be made with the generator or starting motor on the car. With the generator or motor on the bench, the spring tension may be easily checked by using a spring-balance-type scale of, say, 5-lb. capacity, connected to the brush, as shown in Fig. 572. This illustration shows the procedure used in checking starting-motor brush tension, but the same applies to the generator. The spring tension may usually be adjusted to the proper

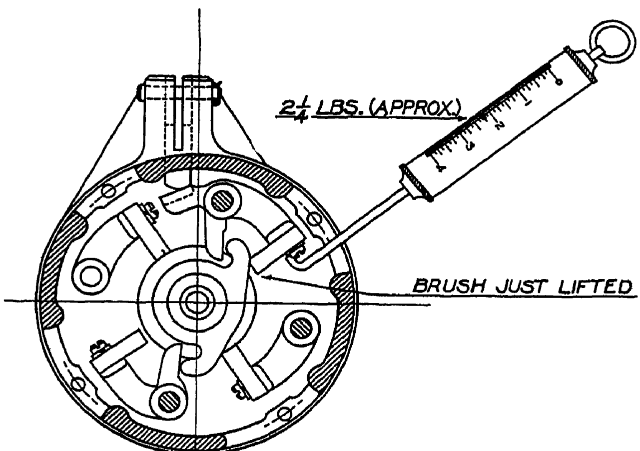


FIG. 572.—Method of testing starting motor brush spring tension.

value by increasing or shortening the length of the spring or by bending. The same general procedure applies to all makes of generator and starting-motor equipment.

395. Brush Holders.—The design of the brush used in generators and in starting motors is governed largely by the method of holding it in position. Two general styles of brush mountings are used, one in which the brush operates through a rectangular-type holder, as in Fig. 573, the other in which the brush is attached rigid to the end of a brush arm, as in Fig. 574. Where the brush holder, as shown in Fig. 573, is used, electrical connection is made to the brush itself by a flexible wire, commonly referred to as brush "pig tail." The purpose of this connection is to avoid

excessive current flowing through the brush spring, which might cause it to heat up and lose its spring tension.

In the arrangement shown in Fig. 574, no flexible brush lead is required, the current being conducted to and from the brush by the brush arm. In some cases, however, a flexible lead is used connected to the brush arm to avoid the passage of current through the brush-arm pivot.

In the third-brush type of generator the holder for the field control or third brush is made adjustable, so that it can be shifted around the commutator so as to advance or to retard the brush position. This type is illustrated in Fig. 573, which shows the end housing and the brush mounting for the Ford generator. Should a shifting of the third brush be necessary, it is always well to check the brush contact and to sand-in all brushes that do not make perfect running contact, in order to insure the best generator operation.

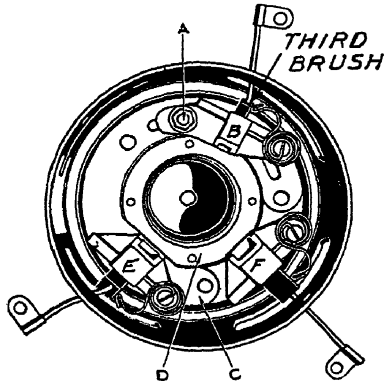


FIG. 573—End-housing and brush holder assembly for Ford generator.

396. Procedure in Fitting Brushes to Commutator.—When the installation of a new brush becomes necessary, care should be taken to select the type, size, and quality of brush recommended for the generator or the motor by its manufacturer.

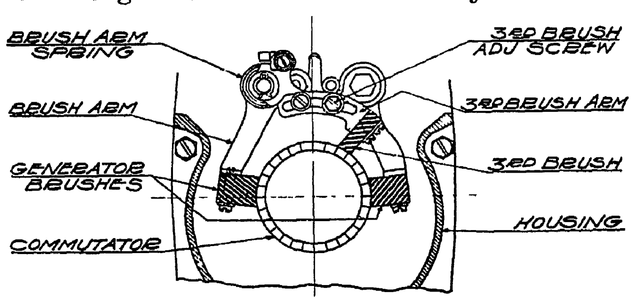


FIG. 574.—Brush assembly on Hudson-Delco generator, showing brushes attached to brush arms.

Each new brush installed should be ground or "sanded-in," so that it makes a perfect fit with the commutator throughout the entire brush-contact surface when the brush is in position and subjected to its normal spring tension. The same applies to old brushes that have been adjusted.

This may be done, using No. 00 sandpaper, as follows: Cut a strip of sandpaper slightly wider than the brush and insert it between the commutator and the brush with the sand side next to the brush. Then, with the strip passing part way around the commutator, as in Fig. 575*A*, draw it back and forth under the brush until the brush is ground to the same curvature as the commutator. Avoid pulling the strip out straight, as in Fig. 575*B*, as this will round off the brush corners.

If the brush should extend through the holder, and is not rigid with it, the sanding should be done only in the direction of armature rotation; that is, the spring tension on the brush should be relieved when the sandpaper is being drawn in the direction opposite to normal armature rotation.

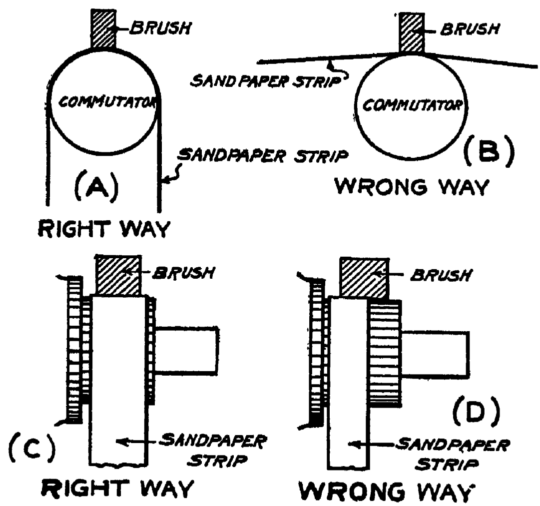


FIG. 575.—Method of sanding in brushes to fit commutator.

In some generators or motors where the opening in the brush cover is small and the brushes and the brush lead connections are somewhat crowded, the brushes can best be sanded-in with the sandpaper glued to the commutator. To do this, the armature is removed and a strip of sandpaper cut so as just to reach around the commutator with the ends meeting along a diagonal line. It is then glued to the commutator with the sand side out and left wrapped with string or tape until the glue is dry. The armature is then reassembled in the machine, with the brushes in position, and is rotated in the direction of normal rotation until the brushes seat properly. It is then taken out, the sandpaper removed, and the glue cleaned off the commutator, using the sandpaper. The corners of the brushes should not be broken when replacing the armature.

SECTION XXV

TYPICAL STARTING AND LIGHTING SYSTEMS—TWO-UNIT TYPES

397. Electrical Symbols and Methods of Tracing Circuits.—In the following two sections, which include a number of circuit diagrams for typical single-unit and two-unit starting and lighting systems, various symbols are used to aid in tracing the various circuits. These symbols are shown in Fig. 576. As an aid in the tracing of circuits, it would be well to bear in mind that such circuits as the shunt-field circuit, the voltage-coil circuit of the cutout, and charging circuits should be traced, starting at the positive brush of the generator and returning to the negative.

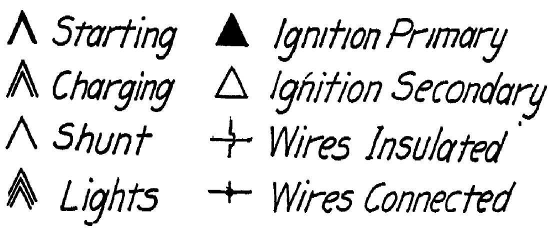


FIG. 576.—Symbols used to indicate electrical circuits.

On the other hand, the starting circuit, the lighting circuits, the horn circuit, and the primary ignition circuit should be traced, starting from the positive terminal of the battery and returning to the negative. As will be noted from Fig. 576, the single light-weight arrowhead indicates shunt circuits, while the heavy-weight arrowhead indicates starting circuits. Double arrowheads indicate charging circuits, while the three arrowheads indicate lighting circuits.

398. The Auto-Lite Starting and Lighting System.—Typical Auto-Lite generators are shown in Fig. 577. Model GH shows the square type of generator, which has been widely used, while Model GK shows the round type. The early models of Auto-Lite equipment, such as Models GD and GF, operate on

the principle of reverse-series regulation. (The circuits of Model GF were shown in Fig. 531.) In the later models, third-brush regulation is used, examples of which will be shown for: (1) the Chevrolet, (2) the Durant, and (3) the Willys-Knight cars.

1. *Auto-Lite System for Chevrolet, Model* 490.—The wiring diagram for the Auto-Lite starting and lighting system, with Connecticut ignition, for the Chevrolet, Model "490," is shown in Fig. 578. The generator is of the two-

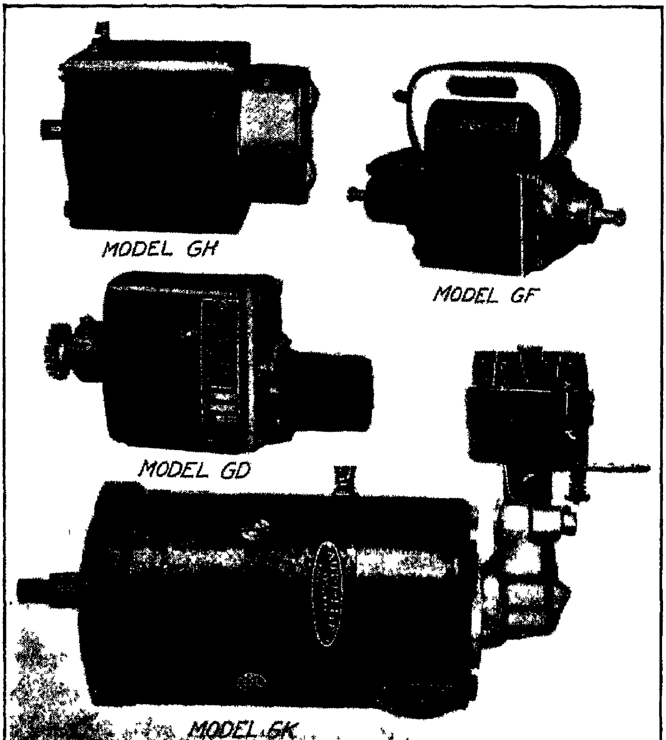


Fig. 577.—Types of Auto-Lite generators.

pole type employing the third-brush principle of regulation. The maximum charging rate of the generator should be 15 amp. at 25 m.p.h. The charging rate may be increased or decreased by shifting the third brush in the same direction or in the opposite direction, respectively, to armature rotation. The cutout should be adjusted to close at approximately 6 to 8 m.p.h., or at a voltage of 7 volts. The lighting system is controlled by a Connecticut switch which is mounted on the same panel with the automatic kick-out ignition unit. For dimming, the headlights are connected in series by the switch.

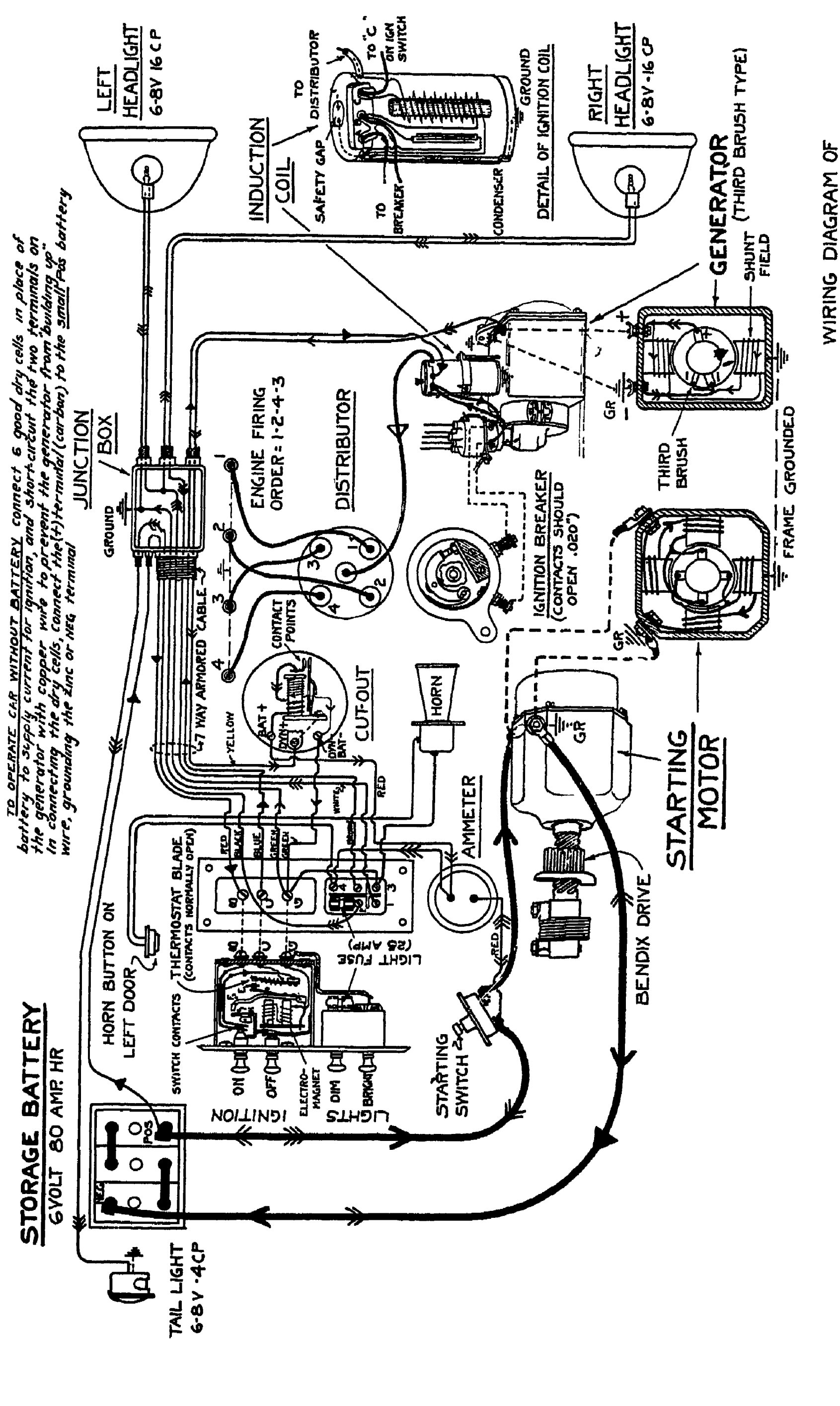


FIG. 578.—Circuit diagram of Auto-Lite starting and lighting system with Connecticut ignition on Chevrolet model "490" (1920).

2. *Auto-Lite System for Durant, Model* 22*A* (1922).—In general appearance, the generator in this system is similar to Model GH shown in Fig. 577, being a square-type two-pole machine. A circuit diagram for the system is

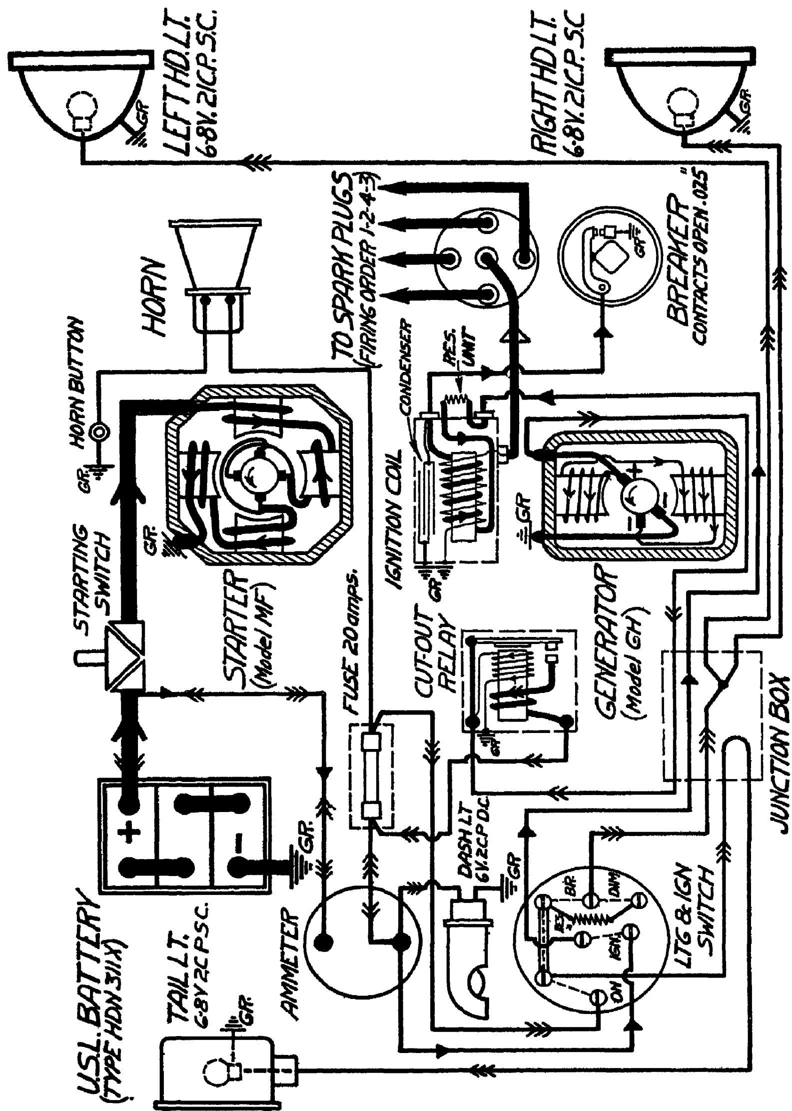


FIG. 579.—Circuit diagram of Auto-Lite system for Durant, model 22A (1922).

shown in Fig. 579. The operation of the system is similar to that described for the Chevrolet, except that the headlights are dimmed through a dimmer resistance unit, instead of through the series method.

The generator should be so adjusted that when cold it will start charging at approximately 550 to 600 r.p.m. It should generate 8 amp. at 900 r.p.m. and attain a maximum of 16 amp. at 1,700 r.p.m. When the generator is motoring freely it should draw 2.7 amp. at 6 volts, the field current alone being 1.7 amp.

The starting motor is of the four-pole four-brush type and when running freely should draw approximately 40 amp. However, when cranking the engine at approximately 110 r.p m., it should draw 120 to 160 amp. at 5.5 volts. On the lock-torque test, it should deliver 10 lb.-ft , drawing approximately 400 amp. at 4 volts

3. *Auto-Lite System for Willys-Knight.*—The Auto-Lite generator and starting motor used on the 1923 Willys-Knight are shown in Fig. 577 (Model GK) and Fig 580 respectively. The wiring diagram for the complete system is shown in Fig 581. This is representative of the Auto-Lite system

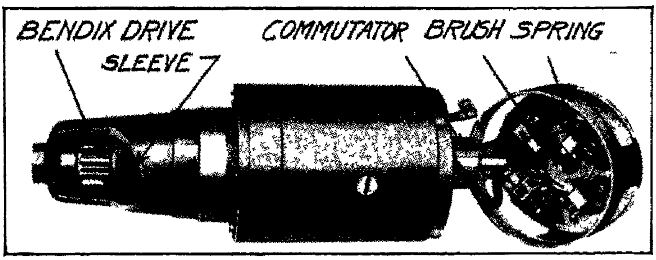


FIG. 580.—Auto-Lite starting motor used on Willys-Knight, Model 20.

using round-type generators and starting motors as furnished on many other cars. As will be noted, regulation is through the third-brush principle. Except that the generator is of the four-pole construction, the operation of the system is similar to the other Auto-Lite systems previously described.

399. Bijur System for Packard "Twin Six."—The Bijur starting and lighting system as found on the Packard "Twin Six" is a practical application of voltage regulation through vibrating-type relay, as explained in Art. 366, Sec. XXII, Fig. 537. The generator used is the same as that shown in Fig. 539, the circuits being as shown in Fig. 540.

The starting motor is of the four-pole construction, the circuits being as shown in Fig. 582. The wiring for the complete system for the Packard, including Delco ignition, is shown in Fig. 583. As explained in Art. 367, Sec. XXII, the regulator should be adjusted so as to maintain the generator-brush voltage constant at 7.75 volts. With the generator-brush voltage constant, the charging rate will vary with the condition of the battery. For a

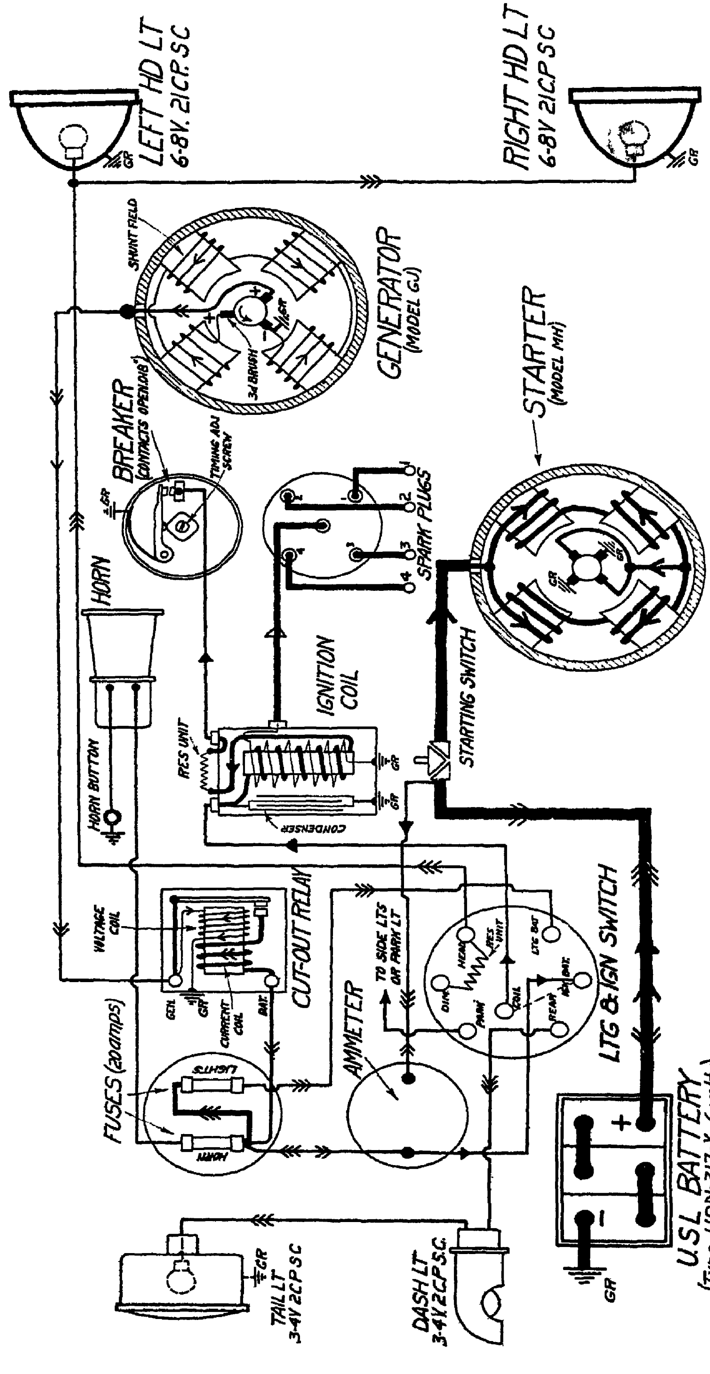


Fig. 581.—Circuit diagram of Auto-Lite system for Willys-Knight, model 64–67 (1923)

discharged battery in which the countervoltage is approximately 5.4 volts, the charging rate will be approximately 15 to 20 amp., but will taper off as the battery becomes charged, so that for a fully charged battery in which the countervoltage is approximately 6.6 to 7 volts, the charging rate will reduce to approximately 4 to 6 amp.

To increase or decrease the maximum charging rate, the spring tension of the regulator should be slightly increased or decreased, respectively. This is a delicate adjustment and should not be attempted by anyone not thoroughly trained in this work.

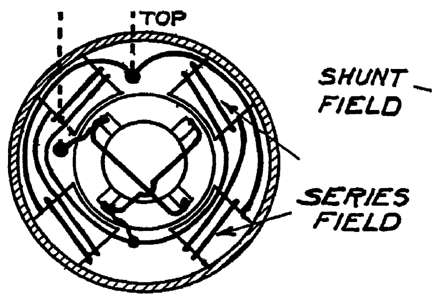


FIG 582.—Circuit diagram of Bijur starting motor used on Packard "Twin Six"

400. American Bosch System for Essex, Model A.—The Bosch generator, such as used on the Essex, Model A, is shown in Fig. 584. The starting motor was shown in Fig. 555*F*, Sec. XXIII. As will be noted in a study of the circuits shown in Fig. 585, the generator is of four-pole construction employing third-brush regulation, the cutout as well as the shunt-field fuse being located on top of the generator. The starting motor is also of the four-pole construction, the starting-switch equipment being located on the motor itself as shown in Fig. 555*F*.

The charging rate of the generator, when cold, should reach a maximum of 13 to 14 amp. at 1,700 r.p.m. When the generator is heated up to its normal operating temperature, the charging rate should be reduced approximately 2 amp. The starting motor is designed to crank the engine at approximately 120 r.p.m., at which time the motor should consume 150 amp. at 5 volts. Its lock torque is 12 to 15 lb.-ft. at 3½ to 4 volts.

401. Typical Delco Two-unit Systems.—Typical examples of the Delco two-unit systems will be found in: (1) The Nash Six

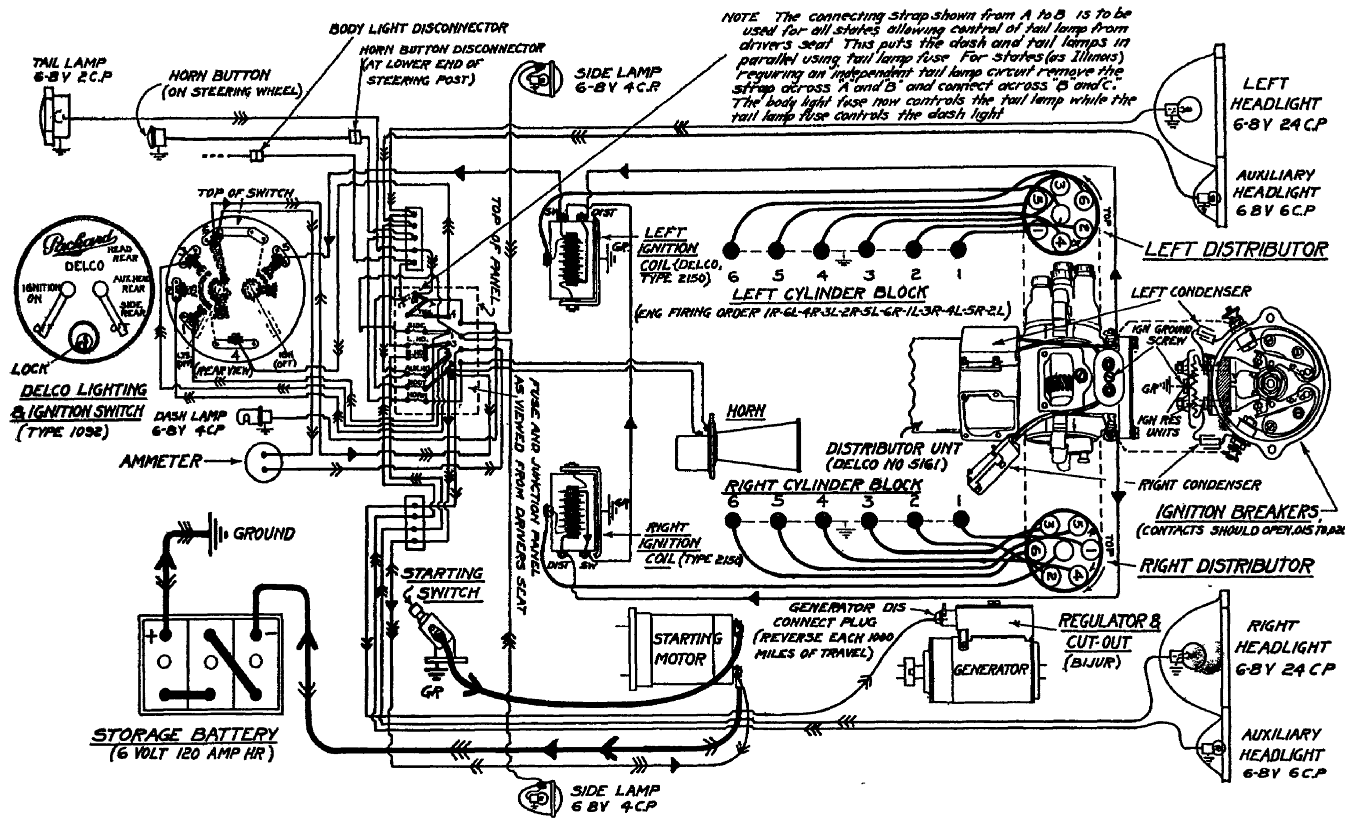


FIG. 583.—Wiring diagram of Bijur starting and lighting system with Delco ignition on Packard "Twin Six," models 3–25 and 3–35.

(1919 model), (2) The Jordan (1923), and (3) the Oldsmobile Six, Model 30, which are described in the order given.

1. *Delco Two-unit System for Nash Six* (1919).—The wiring diagram showing the circuits for the Delco two-unit system, as employed on the Nash Six, 1919 model, is shown in Fig. 586. The installation of this starting and lighting and ignition equipment was shown in Fig. 447

By a study of the circuits shown in Fig 586, it will be noted that no cutout is used in the battery-charging circuit for connecting and disconnecting automatically the generator and battery. Instead of using a cutout, the charging circuit is closed by the turning on of the ignition switch, there being a slight discharge from the battery through the generator windings until the engine speed has increased to the point where the generator voltage is sufficient to charge the battery.

The generator is mounted on the front end of the engine cylinder block and is driven by a V-type fan belt. As may be seen from Fig 586, the

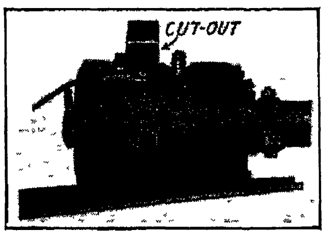


FIG. 584.—Bosch generator used on Essex, model A.

generator is of the two-pole construction employing third-brush regulation. Should the charging rate become too low, before any adjustment is made, care should be taken that the driving belt has the proper tension and is not slipping. The charging rate should reach a maximum of 12 to 14 amp at about 800 to 1,000 r.p.m. of the engine with all lights turned off. This corresponds to 20 to 25 m.p.h. Should the charging rate, however, not reach its maximum until the speed has attained 35 to 40 m p.h., this is an indication that the driving belt is slipping. Another method of determining if the belt is slipping is to turn on the ignition switch (with the engine not running) and note if the generator armature will rotate a part of a revolution. If it does, it is a sure sign that the belt needs greater tension. Care, however, should be taken not to tighten the belt too much, as this may cause injury to the front generator bearing. With the belt at proper tension, the charging rate may be adjusted by shifting the third brush slightly.

2. *Delco System for Jordan, Models MX and H* (1923).—Wiring for the Delco system used on the Jordan Models MX and H is shown in Fig. 587. The generator in this system is also a two-pole third-brush type, being operated in conjunction with a cutout located on top of the generator. The installation of the generator and the starting motor were shown in Figs. 482 and 485, Sec. XIX.

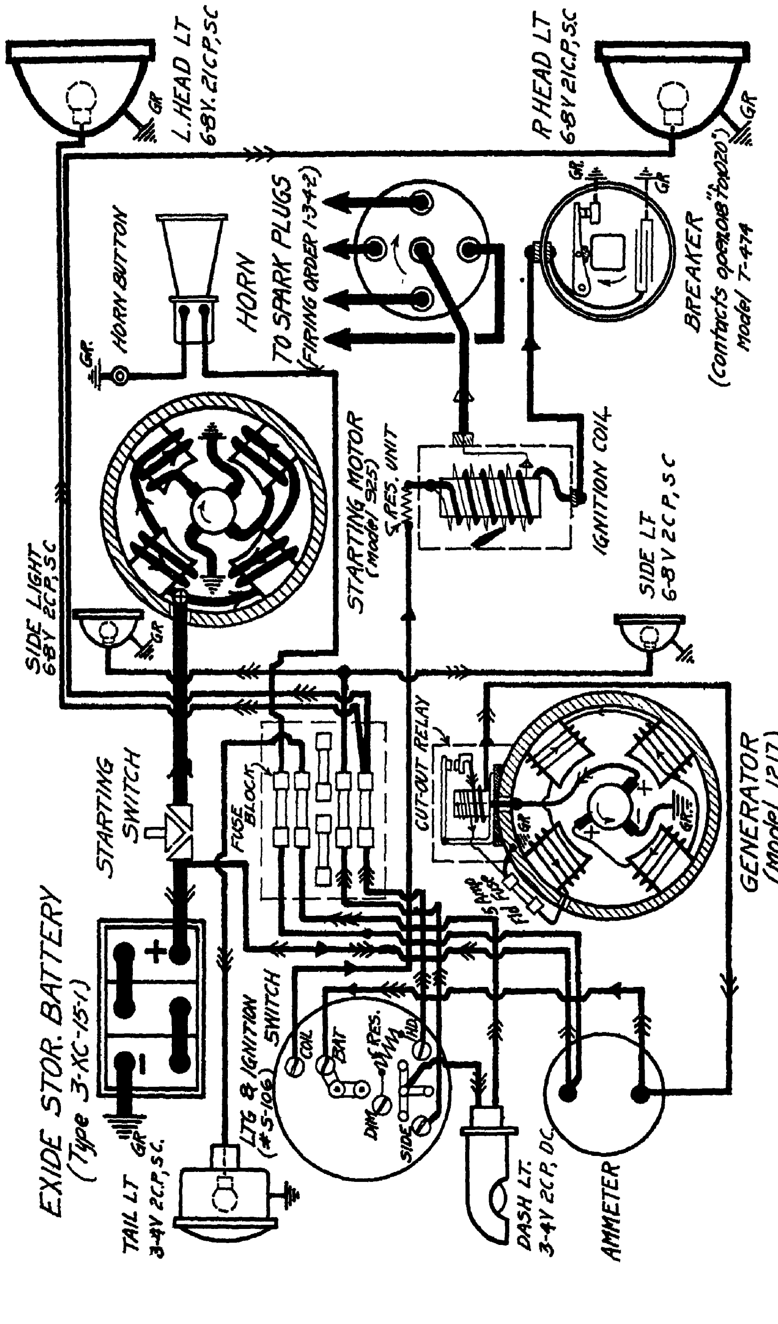


FIG. 585.—Circuit diagram of American Bosch system on Essex, model A (1922).

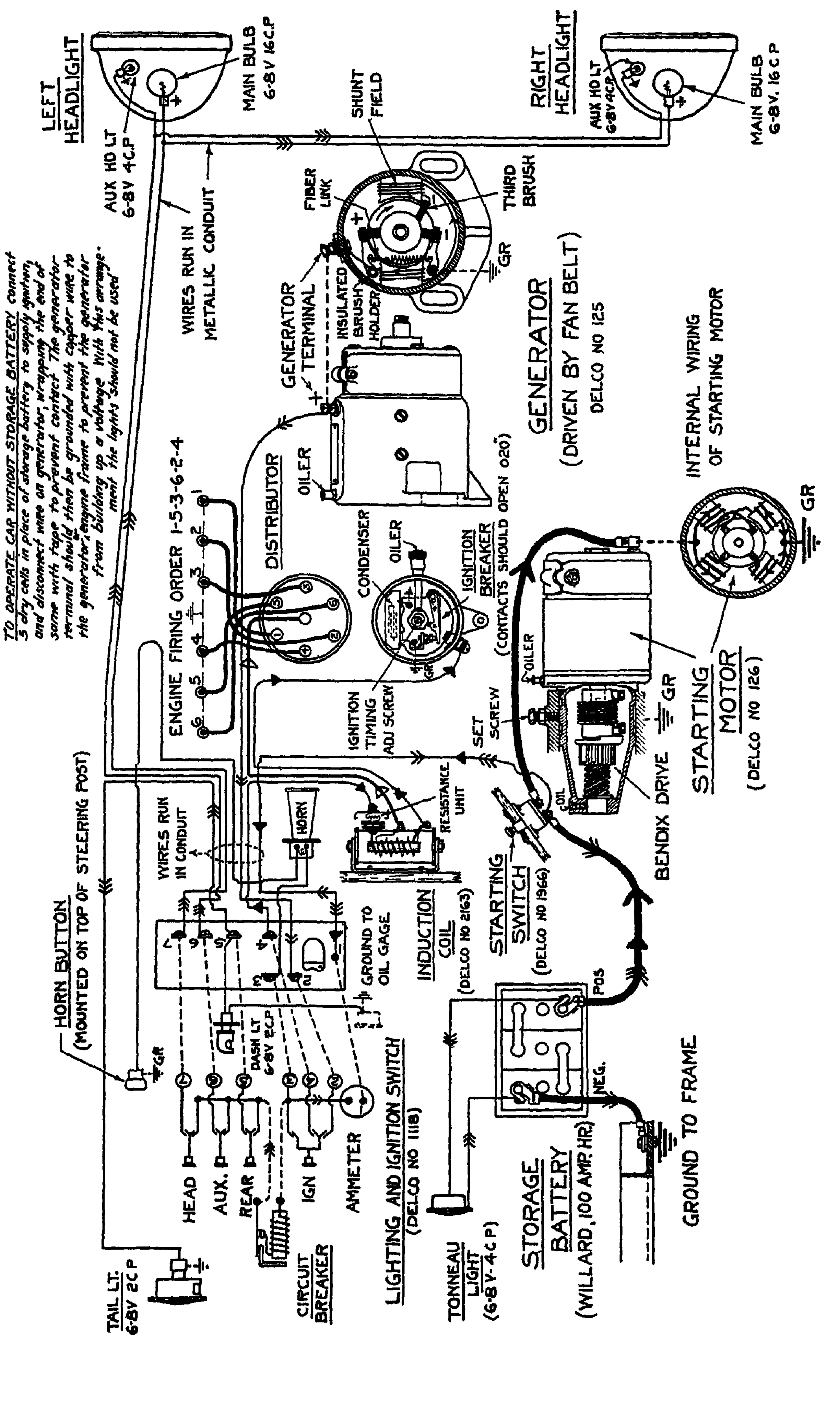


FIG. 586.—Circuit diagram of Delco system for Nash "Six" (1919).

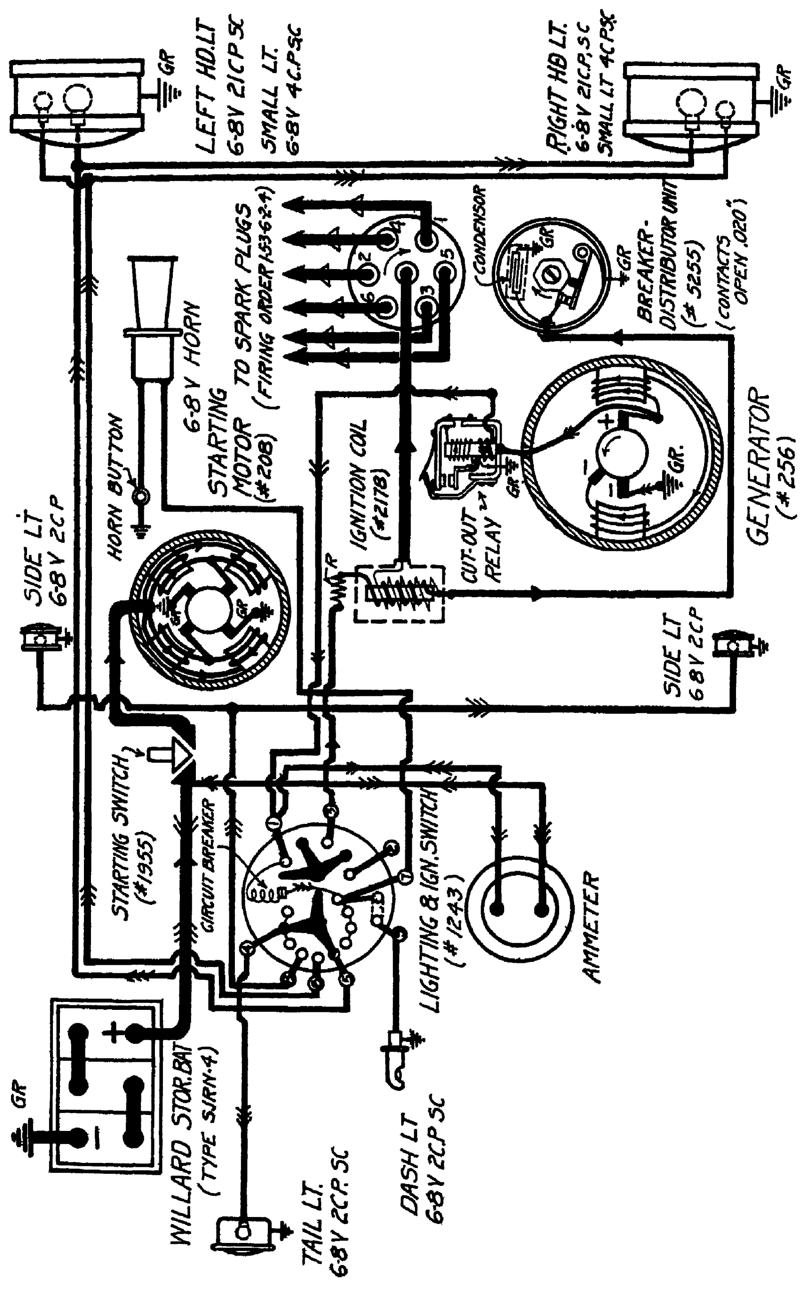


FIG. 587.—Circuit diagram of Delco system on Jordon, models, MX and H (1923).

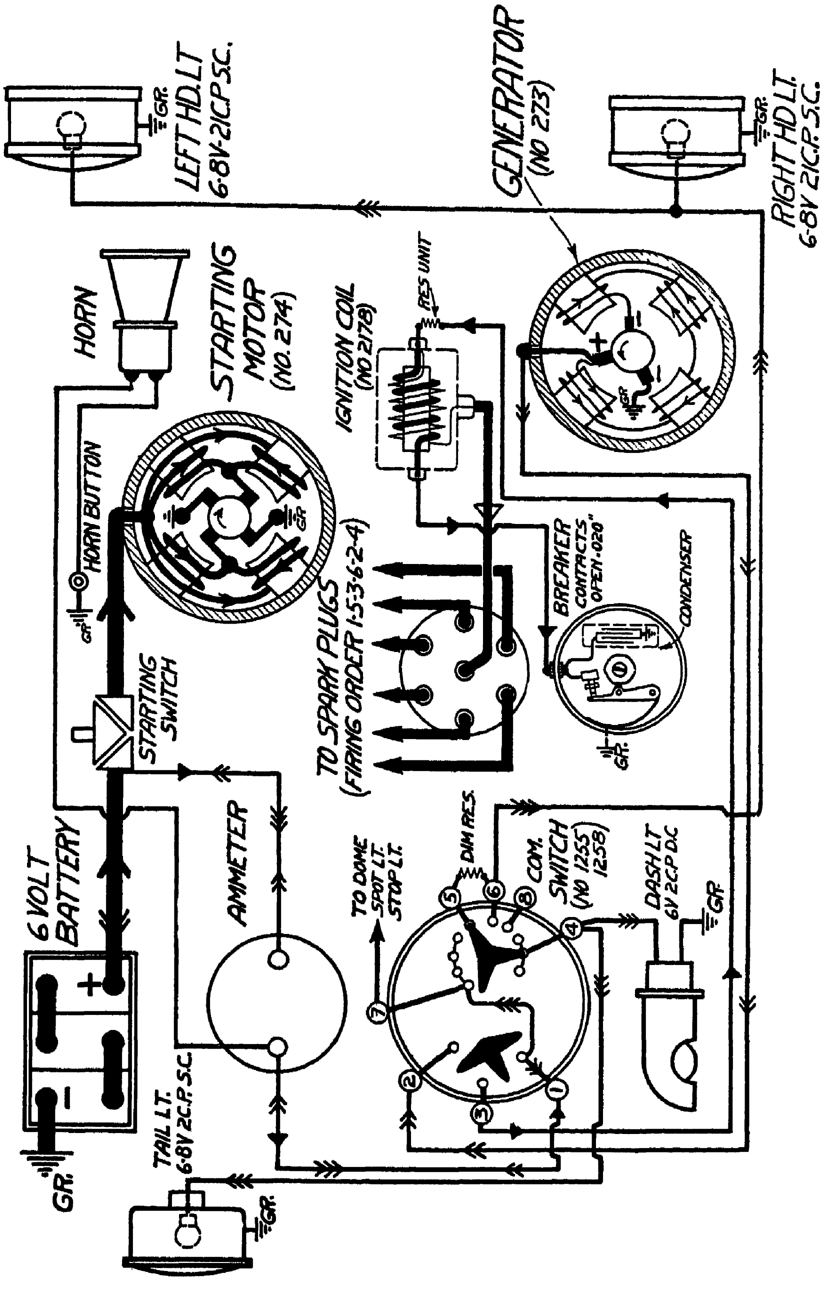


FIG. 588.—Circuit diagram of Delco system on Oldsmobile, model 30 (1924).

The lighting switch is of the round type and has a circuit breaker mounted on the back, which serves as a protective device, taking the place of fuses, should a "ground" occur on the lighting and the horn circuits Should a ground occur, as indicated, the circuit breaker will start vibrating as soon as the discharge through it has reached 25 to 30 amp. Once vibrating, it will continue to vibrate, drawing only 6 to 10 amp. until the ground is removed. It thus serves as a telltale and protective device, preventing the battery from discharging at sufficient rate to injure the wiring.

The generator should give the following performances at normal operating temperature: 5 amp. at 700 r.p.m , 11 amp. at 1,000 r.p.m , 14 to 16 (maximum) at 1,600 r.p.m., and 15 amp. at 1,800 r.p m.

The starting motor is of the four-pole type and should crank the engine at 125 r.p.m , drawing 150 to 175 amp. at 5 volts. Its lock torque should be 26 lb.-ft. at 3 to 4 volts, drawing approximately 500 to 550 amp.

3. *Delco System for Oldsmobile Six, Model* 30 (1924) —The wiring diagram for the Delco system used on the Oldsmobile Six, Model 30, is as shown in Fig. 588.

In this system the generator is of the four-pole third-brush type. No cutout is used, the charging circuit being completed by the turning on of the ignition switch. The charging rate of the generator at normal operating temperatures should be 8 amp. at 1,000 r.p.m., reaching a maximum of 12 amp at 1,600 r p.m.

The starting motor is of the four-pole four-brush type and the lock torque is 10 lb.-ft. at 3.1 volts. When running free it should draw 60 amp. at 6 volts. In many respects the operation of this system is similar to that of the Nash Six previously described; however, the generator is driven direct from the engine instead of through the fan belt.

402. The Dyneto Two-unit System for Packard "Straight Eight."—The wiring for the Dyneto two-unit system as used on the Packard eight-cylinder engine is shown in Fig. 589. The out standing features of this system are that the generator has a peculiar method of winding and of arrangement of the third brush and that the starting motor is of the six-pole two-brush-type construction.

Referring to the circuits of the generator, Fig. 589, it will be seen that the charging current leads through the third brush to the ground, which is unusual. In most third-brush-type generators, lifting of the third brush will prevent the generator from charging, but in this case it will merely throw the heavy and the light shunt-field windings in series with each other, causing them to operate accumulatively. The third brush of this generator should, therefore, not be raised with the engine running, as the voltage and the current output will instantly become excessive and

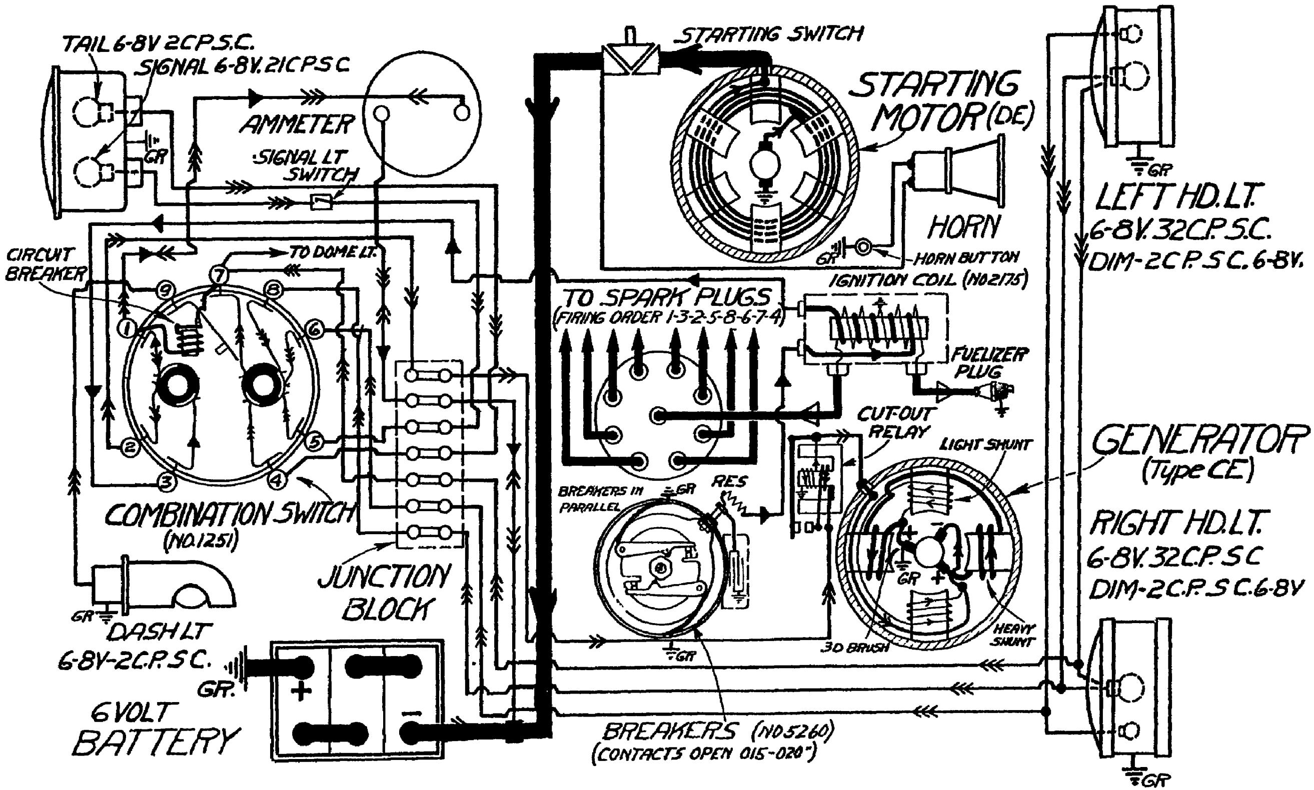


FIG. 589—Circuit diagram of Dyneto starting and lighting system with Delco ignition on Packard "Straight Eight," models 136 and 143 (1923).

endanger the system. The cutout is located on top of the generator and is also of unusual construction, having a three-legged-type core, as shown.

Test Data.—The normal maximum charging rate of the generator should be 16 amp. at 900 r p.m. The light shunt field alone should draw 2 amp. and the heavy shunt field 25 amp. on 6 volts. The starting motor should have a lock torque of 18 lb.-ft. and draw approximately 650 amp. at 3 5 volts. When cranking the engine, the motor should draw 200 amp. at 5.5 volts, and when running free should draw 600 amp. at 6 volts.

The lighting switch of the system is of the Delco type, having a protective circuit breaker mounted on the back of the lighting switch unit. Another unusual feature is the design of the ignition coil, which has a split secondary winding for the purpose of operating both the regular plugs in the cylinders and the fuelizer plug.

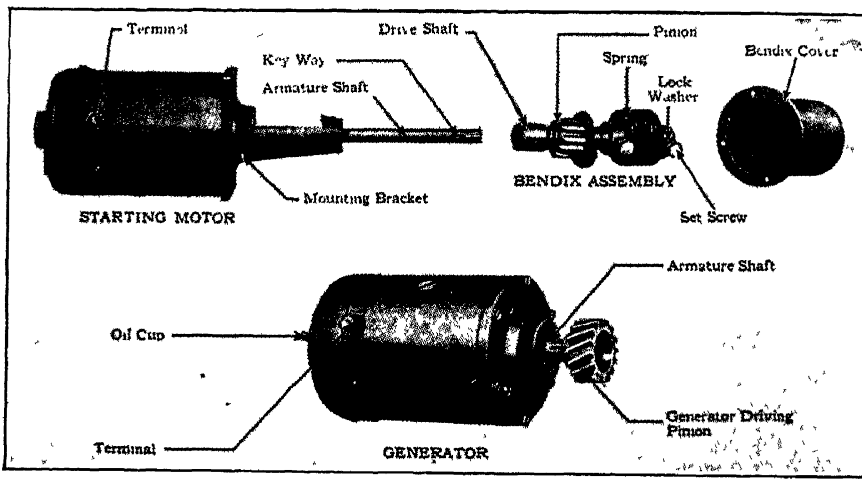


FIG. 590 —Ford generator and starting motor.

403. The Ford Starting and Lighting System.—The Ford starting and lighting system, sometimes referred to as the "F-A Liberty," which has been installed on Ford cars since 1919, is a typical 6-volt system of the two-unit type. The Ford generator and starting motor are shown in Fig. 590. The generator is of the four-pole third-brush type and is mounted on the right-hand side of the engine, being bolted to the timing gear housing, the generator driving pinion meshing directly with the timing gear. The starting motor is also of the four-pole type and is mounted on the left-hand side of the engine, being bolted

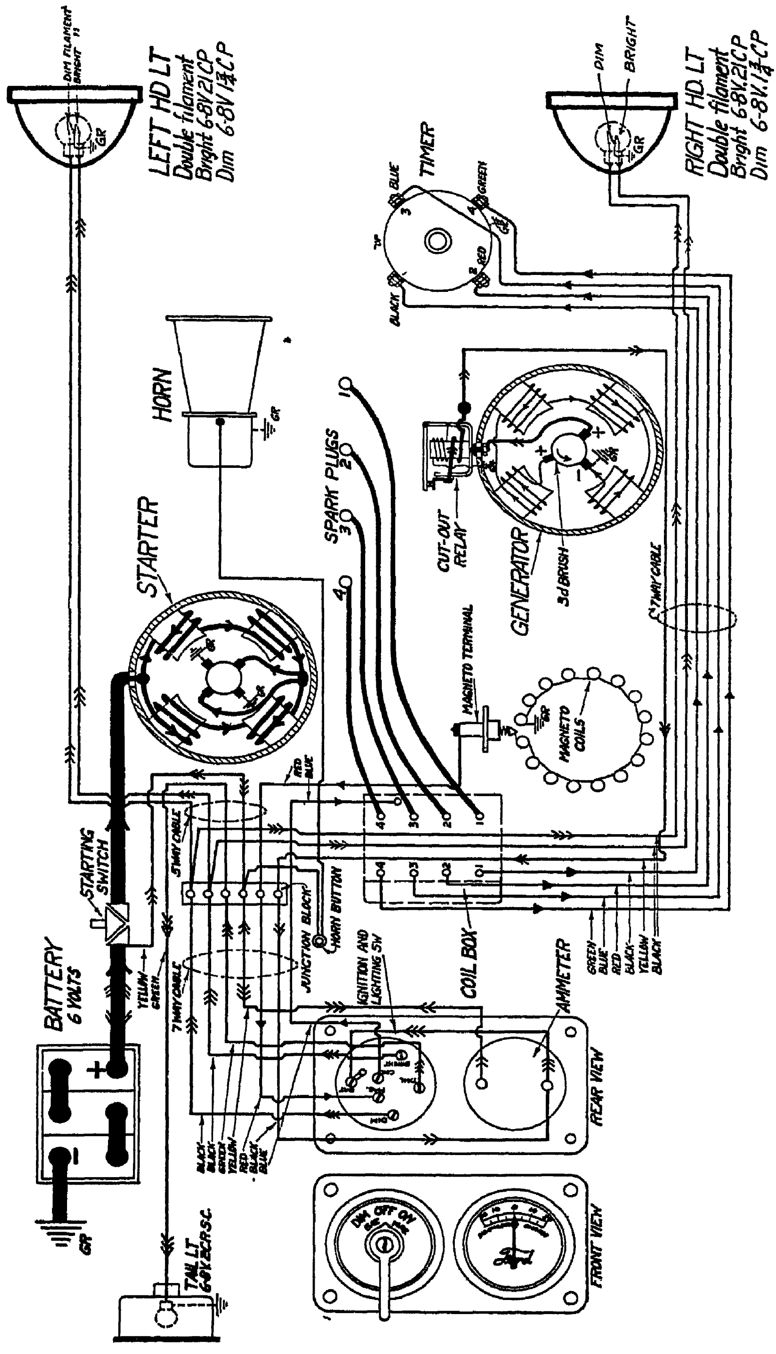


FIG. 591.—Circuit diagram of Ford Electrical system (1924).

to the transmission cover. It is designed to crank the engine through the Bendix drive, a disassembled view of which is shown in Fig. 590.

A circuit diagram of the entire system is shown in Fig. 591. The charging rate of the generator is set so as to cut in at engine speeds corresponding to 8 to 10 miles and should reach a maximum of 12 to 14 amp. at 20 to 25 m.p.h. on direct drive. At higher speeds the charging rate should drop off gradually, due to the characteristics of third-brush regulation.

Lubrication.—Both the starting motor and the generator depend upon the Ford splash system for lubrication. The generator drive-end bearing receives its oil from the timing gear, while the starting motor receives its oil from the flywheel housing. In addition, an oil cup is provided for the generator bearing at the commutator end, which should receive a few drops of light high-grade oil about once each 500 to 1,000 miles of travel. The other bearings need no attention.

Caution!—As may be seen from the diagram of the complete system, shown in Fig 591, the magneto and battery terminals, indicated as Nos 2 and 3 on the junction block, come very close together. And, since the introduction of the battery current into the magneto winding may weaken or discharge the magneto, care should be taken when working on the electrical system not to "short" accidentally between these two terminals A good plan is to disconnect the positive battery terminal, should repairing in the electrical system be necessary

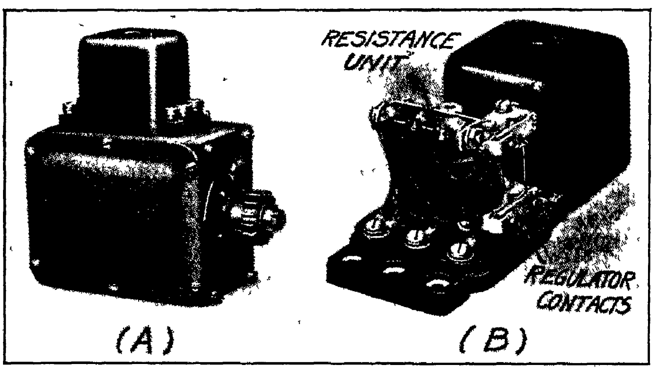


FIG. 592—Gray & Davis generator and regulator-cut out, type T.

404. Gray & Davis System, Type T, for Paige—(1916).—The Gray and Davis generator, type T, and cutout, which was used on the 1915 and 1916 Paige and many other cars, is shown in Fig. 592. The starting motor usually used in conjunction with it was shown in Fig. 555*D*, the principle of which was shown in Fig. 486.

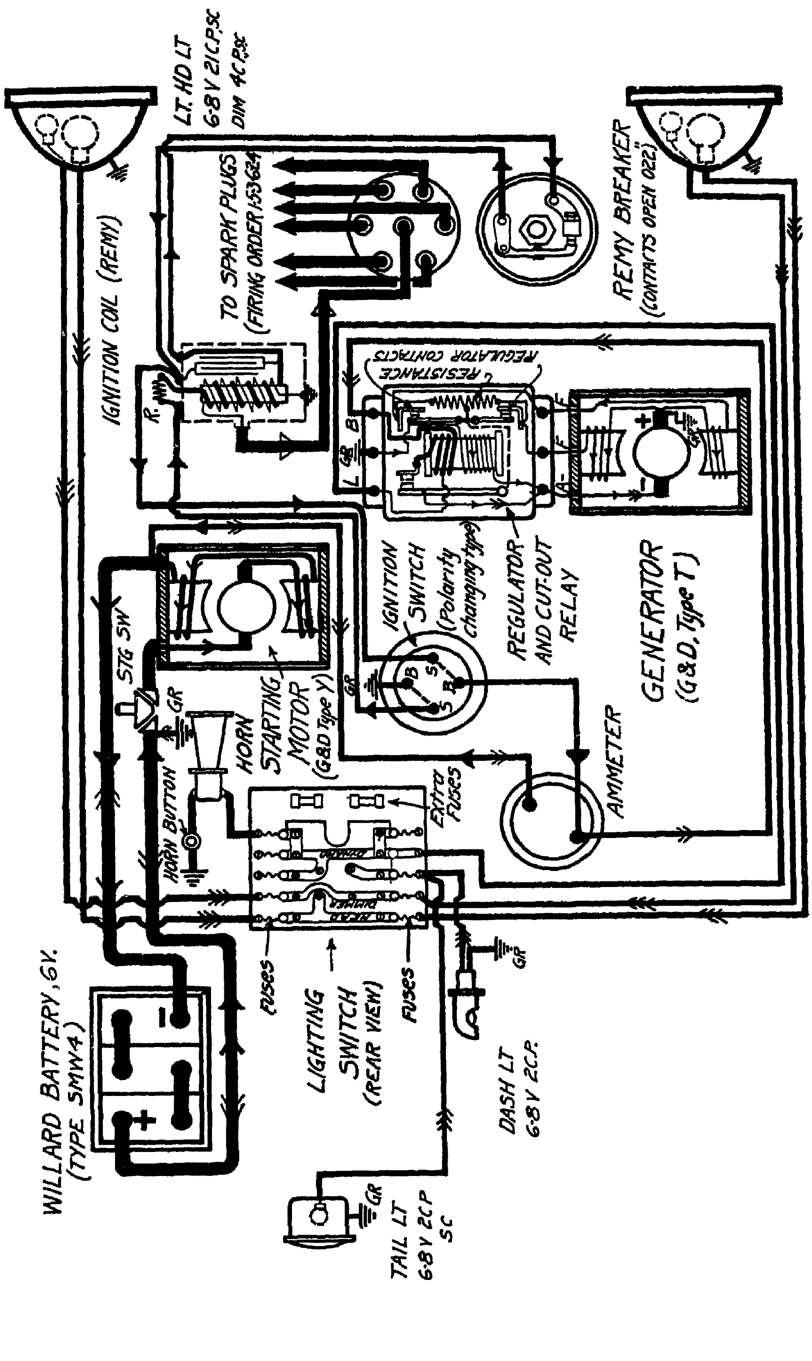


FIG. 593.—Circuit diagram of Gray & Davis starting and lighting system with Remy ignition on Paige, model 6–46 (1916).

The wiring diagram of the system, Fig. 593, shows that the generator is of the two-pole box type operating with a vibrating-type regulator. The regulator unit which is mounted on top of the generator serves both as a regulator to control the charging rate and as a cutout. There are two sets of regulator points, both of which are intended to operate simultaneously, each pair of contacts being in parallel with half of the regulating resistance unit.

A special feature of this regulator is that the wire which carries the lighting current is tapped into the middle of the current-coil winding. This has the effect of boosting the output of the generator when the lamp load is on. The normal charging rate of the generator should be 10 to 12 amp. maximum reached at 1,000 r.p.m. With the lights turned off, regulation should begin at approximately 18 to 20 m.p h., while, with the lamps turned on, regulation should take place at approximately 22 to 23 m.p.h. This is brought about by the action of the lighting current passing through part of the current-coil winding of the relay, the effect being to oppose the magnetic pull of the voltage-coil winding.

The starting motor should crank the engine at approximately 100 r.p.m., drawing 100 to 125 amp. at 5½ volts. When the motor is running free, it should draw 35 amp. at 6 volts.

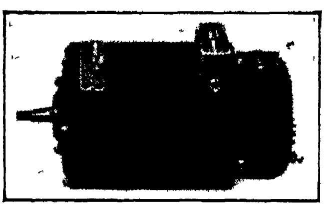


FIG. 594.—North East generator, model L, used on Reo, model T6.

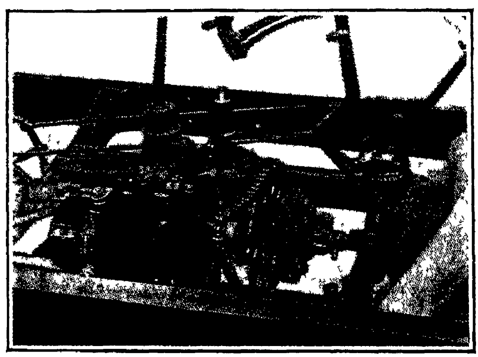


FIG. 595.—Installation of North East starting motor, model R, on Reo, model T6

405. The North-East Electric System on Reo, Model T6 (1923). The North-East generator and starting motor, Models L and R, respectively, as used on the Reo, Model T6, are shown in Figs. 594 and 595. From Fig. 595 it will be noted that the starting motor is mounted on the right-hand side of the transmission and operates through a silent chain to the propeller shaft. The starting mechanism is shown in Fig. 596.

The circuit diagram for the complete system is shown in Fig. 597. The system operates much like other two-unit systems where a third-brush-type generator is employed. Under normal conditions the generator should attain a charging rate of 12 to 14 amp. at 25 to 28 m.p.h. with lamps off. At higher speeds the charging rate should drop gradually, due to the characteristics of third-brush regulation.

On account of the unusual design of the starting mechanism, the method of cranking is different from most cars. In cranking the engine by the

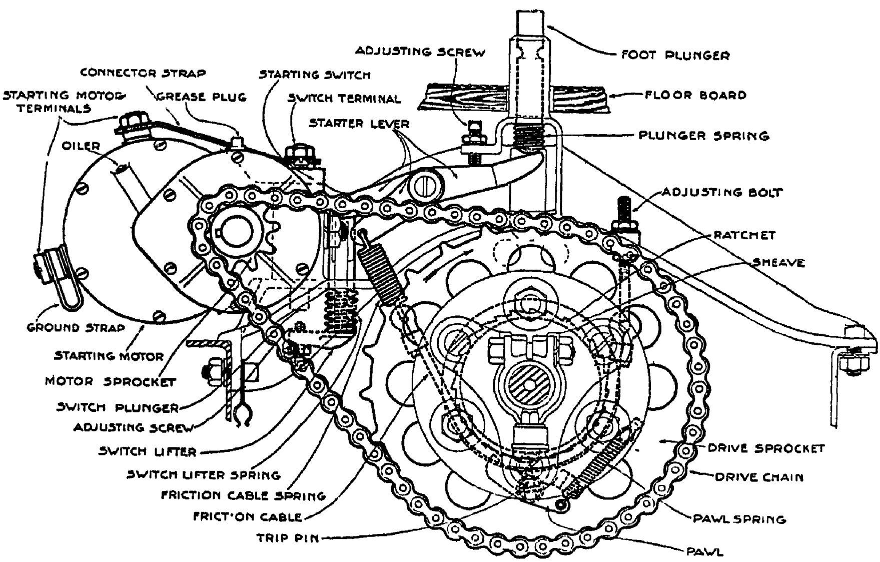


FIG. 596—Starting mechanism on Reo T6.

starting motor, the clutch pedal should be in the driving position, the gear-shifting lever in neutral (the starter cannot be operated with the gears in mesh), and the spark lever fully retarded. The ignition switch can then be turned on, and the starter push rod pressed down (holding the switch closed) until the engine begins to run under its own power. When the engine picks up and begins to run under its own power, the ratchet, Fig. 596, will be revolved faster than the sheave and the sprocket and the pawl will be thrown out of engagement. As soon as this occurs, the starter push rod should be released at once, so as to remove the tension from the friction cable. This entirely disconnects the starting motor mechanically as well as electrically and permits it to remain inoperative until it is again necessary to crank the engine.

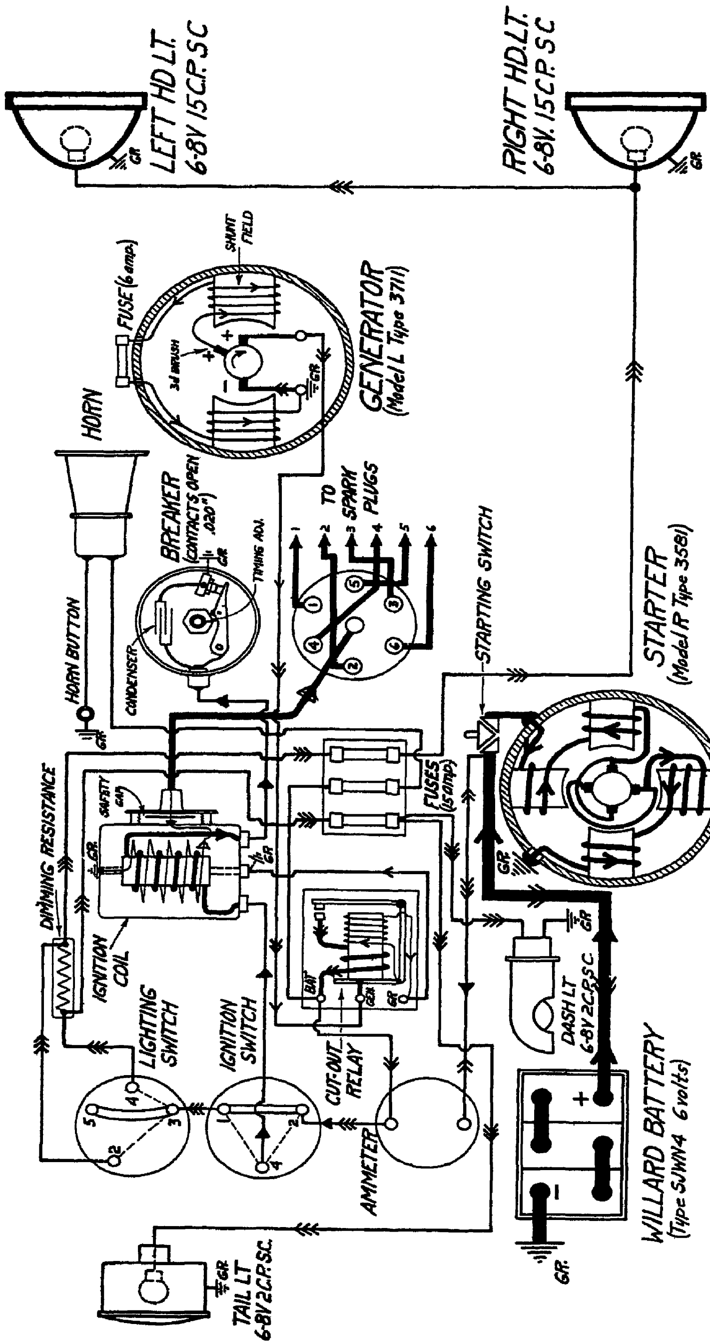


FIG. 597.—Circuit diagram of North East system on Reo, models T6 and U6 (1922).

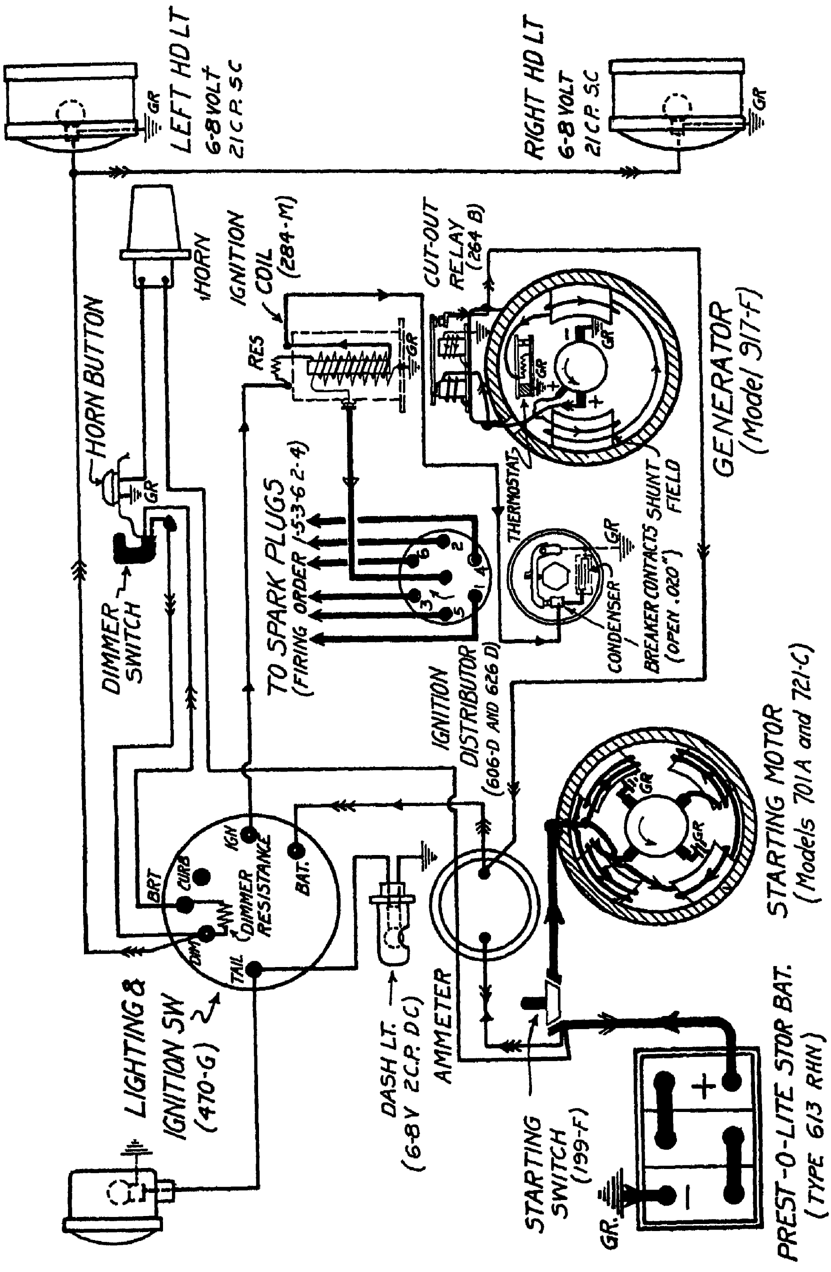


FIG. 598.—Circuit diagram of Remy system on Oakland, model 6–44 (1923).

406. Remy System for Oakland, Model 6-44 (1923).—The Remy system as used on the Oakland, Model 6-44, is a practical application of third-brush regulation in combination with thermostatic control as described in Sec. XXII. The wiring for the system on the Oakland is shown in Fig. 598. The generator is of

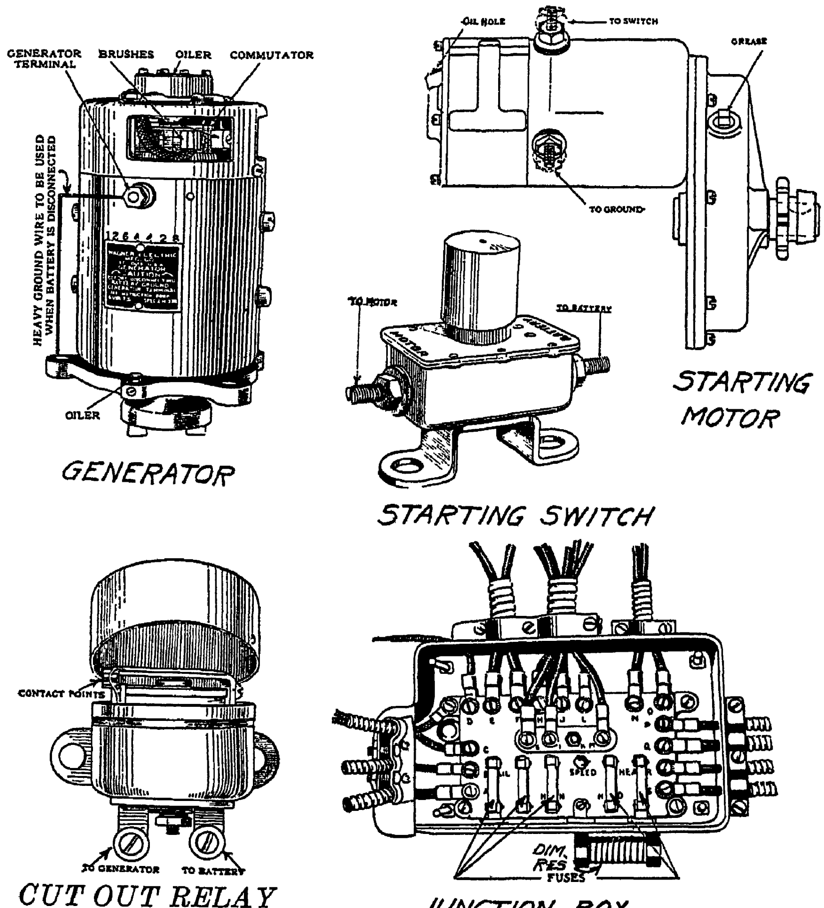


FIG. 599.—Principal parts of Wagner starting and lighting system used on Studebaker.

the two-pole type with the cutout relay mounted on top (see Fig. 549). The regulation is by the third-brush principle and can be adjusted by shifting the position of the third brush. The charging rate of the generator should reach a maximum of 19 amp. at 1,800 r.p.m. with the thermostat closed, and 11 amp. at 1,900 r.p.m.

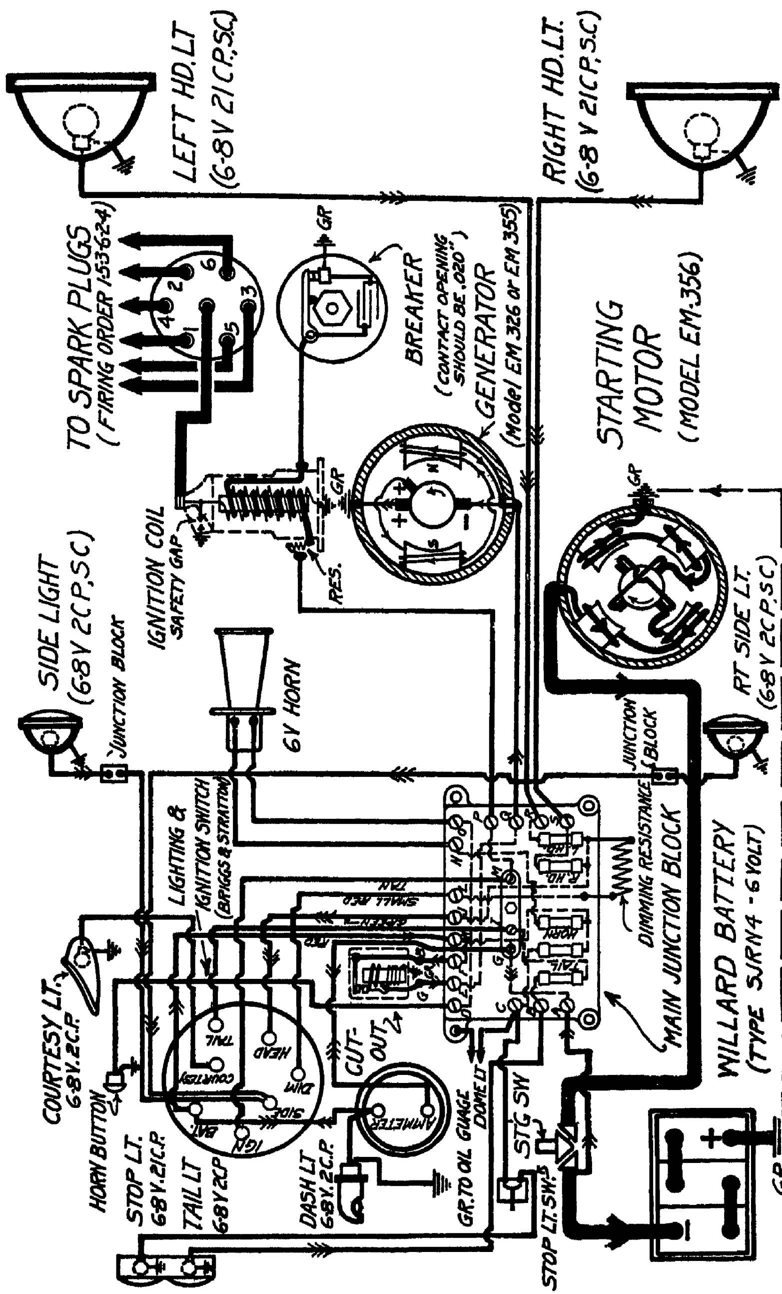


FIG. 600.—Circuit diagram of Wagner system on Studebaker, "Big and Special Six" (1923).

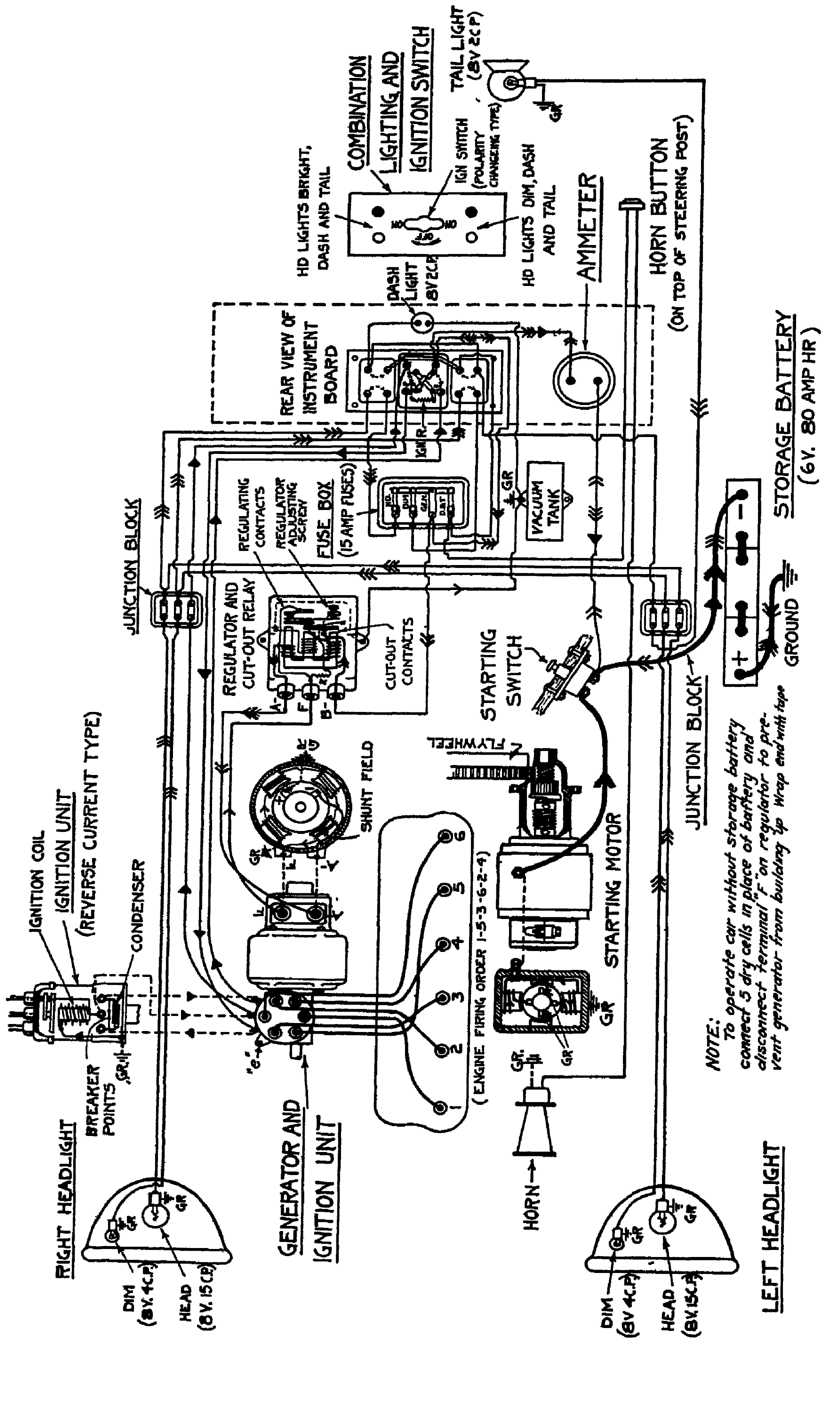


FIG. 601.—Circuit diagram of Westinghouse system on Glide, model 6–40 (1916).

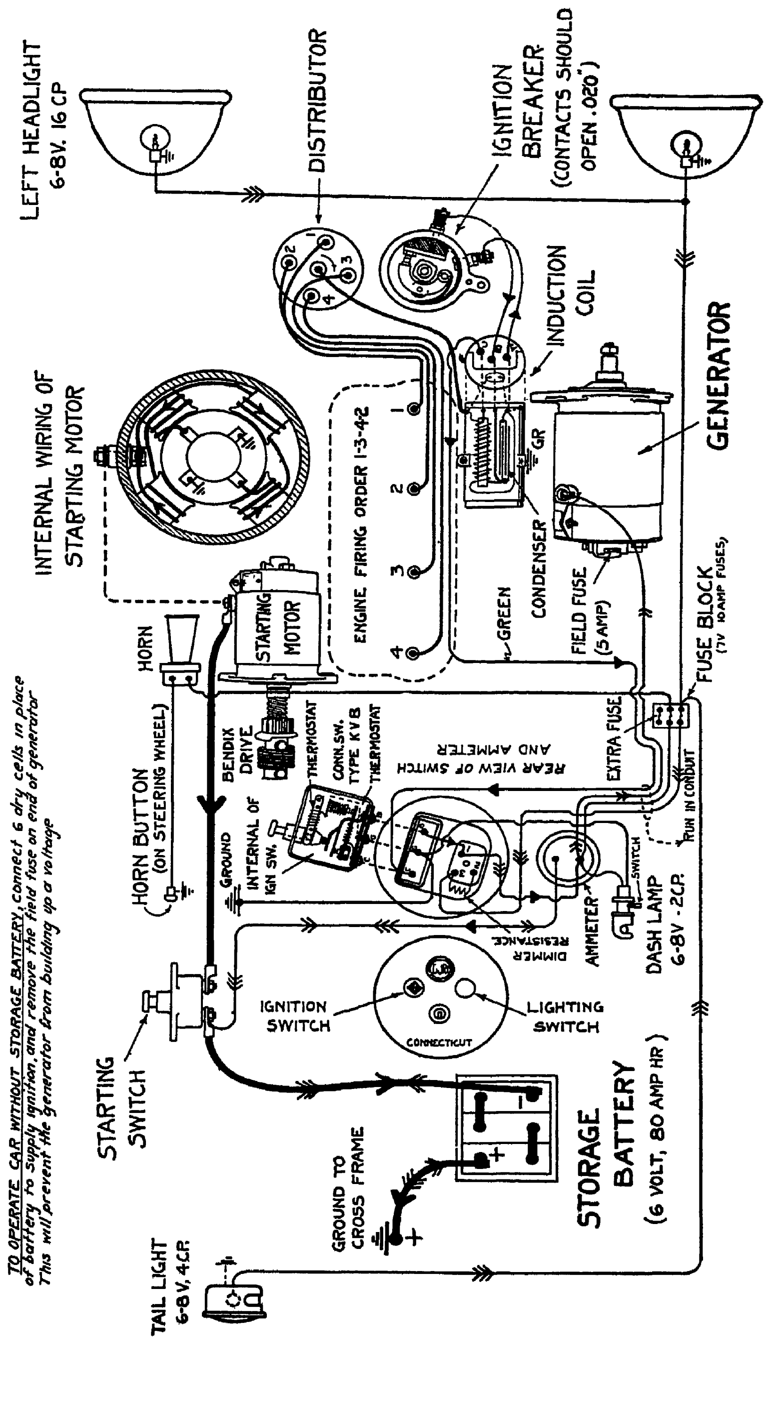


FIG. 602.—Circuit diagram of Westinghouse starting and lighting system with Connecticut ignition on Dort, 1919–1920 models.

with the thermostat open. The thermostat, which is located immediately above the commutator and attached to the end housing, should be adjusted to open at a temperature of approximately 175 deg. F. The cutout should close and the generator start charging at 500 r.p.m.

The starting motor is of the four-pole type, the brushes being grounded as shown. Two models have been used, namely, 701A and 721C. These should have a lock torque of 12 lb.-ft and 16 lb.-ft. respectively.

407. The Wagner System on Studebaker, "Big" and "Special Six" (1923).—The Wagner starting and lighting equipment as used on the Studebaker "Big" and "Special Six" are shown in Fig. 599. The generator is of the vertical type, while the starting motor is of the double-reduction style, cranking through a Bendix gear to the flywheel. Complete wiring of the system is shown in Fig. 600.

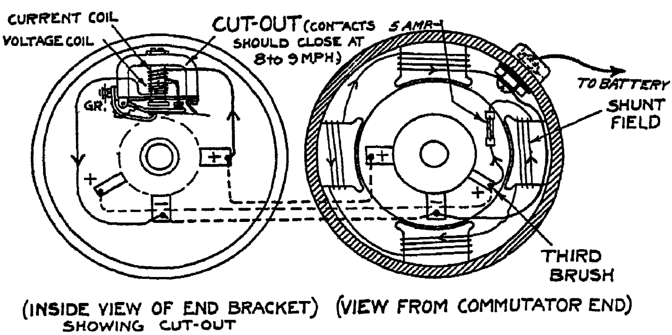


FIG 603.—Internal circuits of Westinghouse generator and cut out used on Dort 1919–1920 models.

The generator is of the two-pole third-brush type. The charging rate should be between 12 and 14 amp. at 2,000 r.p.m., reducing below this value at higher speeds. The starting motor should crank the engine at 110 r p m , drawing 150 to 170 amp. at 5.5 volts. Because of the high-gear reduction, the motor has unusually high-lock torque, namely 35 lb.-ft. The operation of this system corresponds to that of other types employing third-brush regulation.

408. The Westinghouse System.—Typical Westinghouse systems which have been widely used will be found in the electrical installations on the Glide "6-40" and the Dort model of 1919, as illustrated by the diagrams shown in Figs. 601 and 602.

The generator shown in Fig 601 was explained in detail in Sec. XXII. In the system shown in Fig. 602, third-brush regulation is used. The Model 400 generator formerly used had the cutout mounted separately, while Fig.

To obtain the best efficiency and performance from any starting motor in service, it is important that the brushes be of proper quality and make perfect contact with the commutator; that the bearings are properly adjusted and oiled; that the driving pinion meshes properly with the starting gear; and that the starting battery is of proper type and in good condition; and that all connections are clean, tight, and of proper current capacity. It is also assumed that the engine turns freely when cranked.

SECTION XXVI

TYPICAL STARTING AND LIGHTING SYSTEMS—SINGLE-UNIT TYPES

409. Allis Chalmers System on Grant Six, Model P (1915).—The Allis-Chalmers single-unit starter-generator used on the Grant Six, Model *T*, shown in Fig. 604, is a typical starter gener-

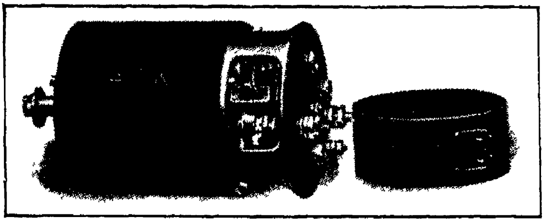


Fig. 604.—Allis-Chalmers starter-generator.

ator of the four-pole, compound-wound, 6-volt type in which the same windings function both as a generator and as a starting motor.

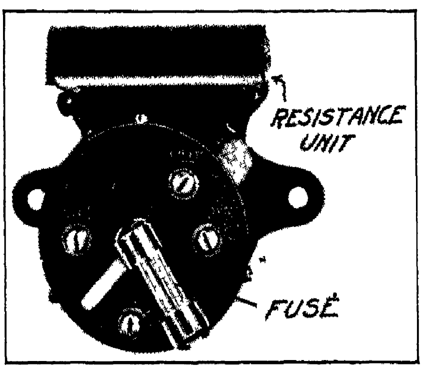


Fig. 605.—Briggs & Stratton regulators used with Allis-Chalmers starter-generator on Grant, model T.

When the unit operates as a generator, regulation is provided through a reverse-series field winding operating in combination with a Briggs and Stratton regulator-cutout, shown in Fig. 605. The complete wiring of the system is shown in Fig. 606. The

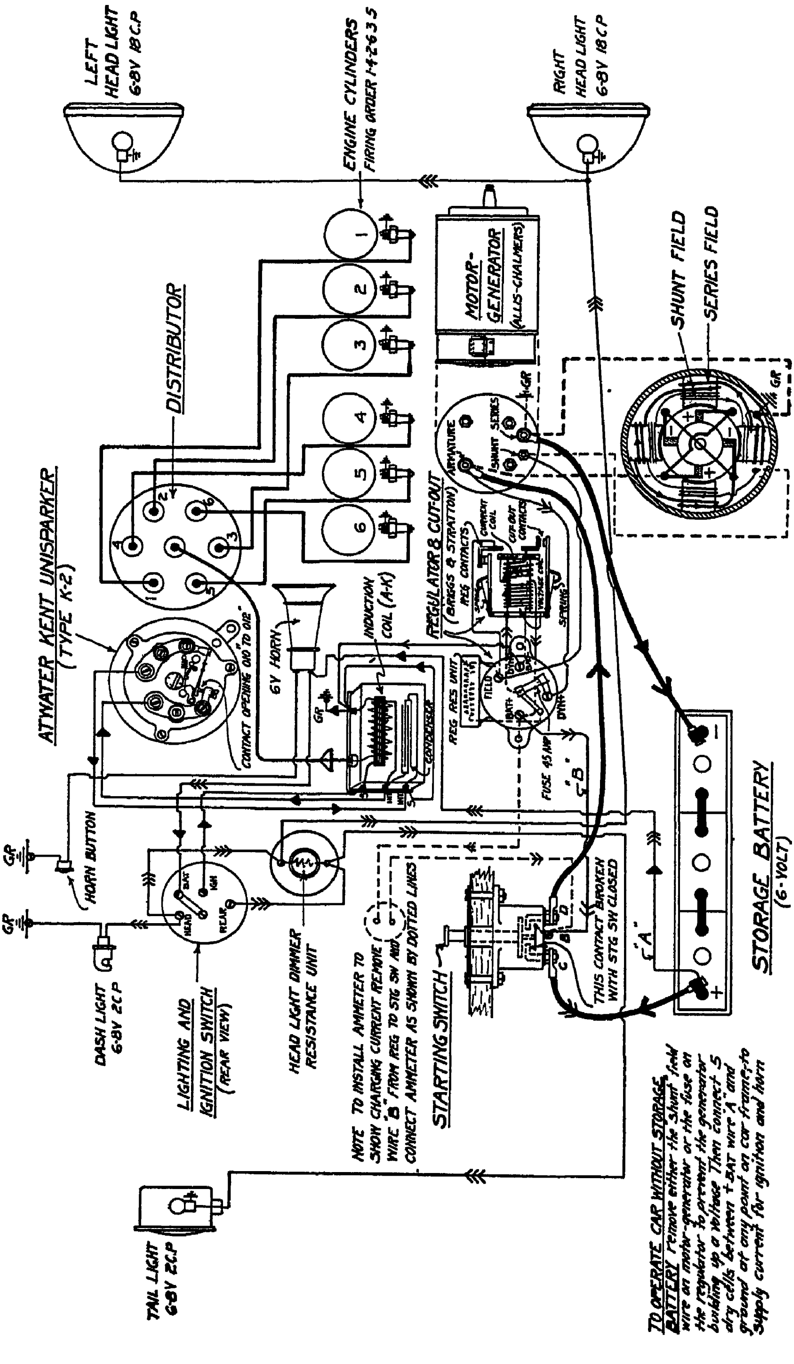


FIG. 606.—Circuit diagram of Allis-Chalmers starting and lighting system with Atwater-Kent ignition on Grant "Six," model T (1915).

regulator-cutout unit operates both as a cutout and as a vibrating-type regulator, employing the principle of combined current and voltage regulation.

The starting switch is of the three-terminal type, the two large terminals *C* and *D* being for starting cable connections, while *B* connects with an auxiliary contact by which the regulator is disconnected from the battery, while the starting switch is closed during the cranking period.

The charging rate should be 10 to 18 amp. with the engine running over 600 r.p.m. Since the generator output depends upon current regulation in combination with voltage regulation, care should be taken to prevent an open occurring in the charging circuit. The cutout should be adjusted to close at 7 to 7½ volts, corresponding to a speed of approximately 10 m.p.h. on high gear.

410. Typical Delco Single-unit Systems.—In all Delco single-unit systems the armature is of the double-wound type, having two commutators and two independent sets of brushes. Typical examples of this type of system will be found in the Buick, the Cadillac, and the Lincoln installations.

1. *Delco System for Buick Six.*—The Delco single-unit motor-generator, as used on the Buick Six, 1917 to 1920 models, is shown in Fig. 160. The unit is mounted on the right side of the engine and is arranged so that it is driven as a generator through an extension of the water-pump shaft connecting with the front end of the armature through an over-running clutch, whenever the engine is in the operation.

At the rear of the motor-generator are the starting gears. These were shown in Fig 492. The starting gears are assembled in the bell housing covering the flywheel and make connection between the armature shaft and the flywheel for the cranking operation. An over-running clutch is built in the largest of these gears to prevent driving of the engine from the flywheel end. With this method of drive, the armature is driven as a generator at one and one-half times crankshaft speed and, due to the slipping of the over-running clutch in the driving end, cranks the engine at a gear ratio of 25 to 1.

A sectional end view of the starter-generator as viewed from the commutator or driving end is shown in Fig. 607. From this figure it will be noted that the small commutator serves for the generator, the third-brush method of regulation being used, while the large commutator serves for the motor, there being two main brushes.

The wiring diagram for the complete system on the Buick 1917–1918 models is as shown in Fig. 608. The wiring is practically the same as for other later models, except that a round-type switch, with connections as

shown in Fig. 609, is substituted in place of the pull-button type switch shown in Fig. 608. The motor-generator performs three operations as follows:

(*a*) Motorizing the Generator.—This operation is necessary in order that the starting gears may be brought into mesh with the small gear on the armature shaft and with the teeth on the flywheel. This takes place whenever the ignition switch is turned on. Turning on the ignition switch completes the circuit from the storage battery to the generator and allows current to be discharged from the battery through both the shunt-field winding and the generator coils on the armature, thus causing the armature to revolve slowly as a shunt-wound motor.

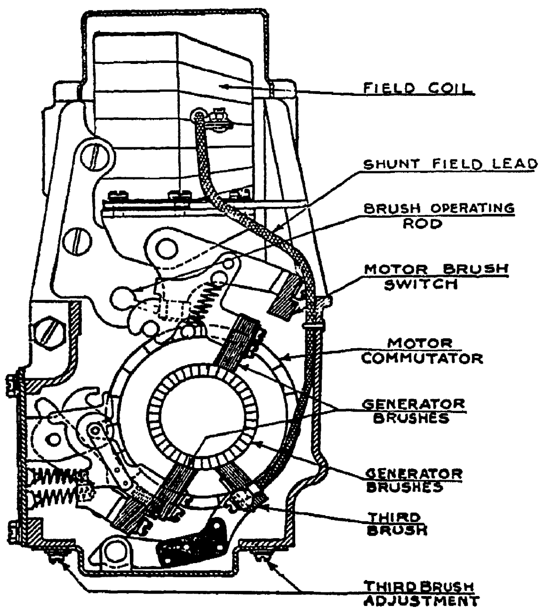


FIG 607.—Sectional view of Delco motor-generator used on Buick "Six" (1917), showing brush arrangement.

(*b*) Cranking Operation.—The cranking operation is performed when the starting gears are brought fully into mesh and the motor brush makes contact with the commutator. As may be seen from Figs. 607 and 608, a push rod, operated from the foot lever, lifts the generator brush at the same moment the starting motor is dropped onto the commutator. Since the upper generator brush is lifted during this operation, the unit functions only as a starting motor, putting into play the series-field winding and the heavy motor winding of the armature. The starting motor brush thus serves as a starting switch.

(*c*) Generating.—After the cranking operation is completed, the starter pedal is returned by a spring as soon as the foot pressure is removed. This

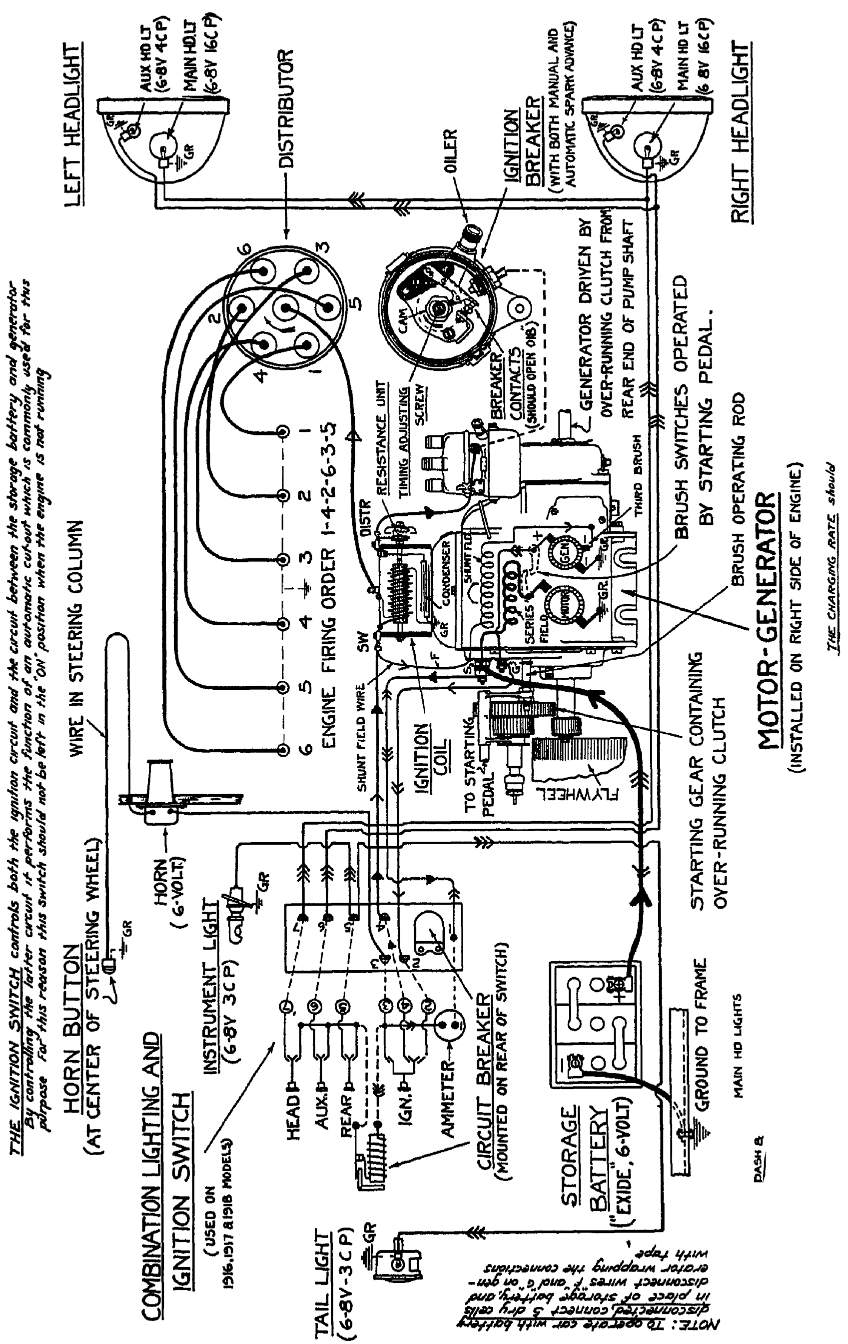


FIG 608.—Circuit diagram of Delco system on Buick "Six"—1917–1919.

disconnects the starting gears, raises the motor brush, and allows the generator brush to make contact with the commutator, thus completing the generator circuits. Since no cutout is used, the voltage generated at low

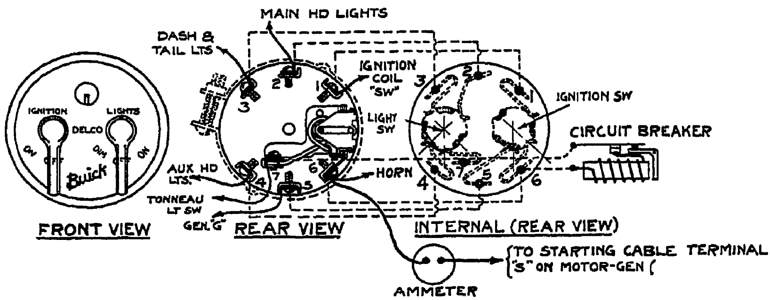


FIG. 609—Connections for Delco round-type switch used on Buick Six, 1920 and later models.

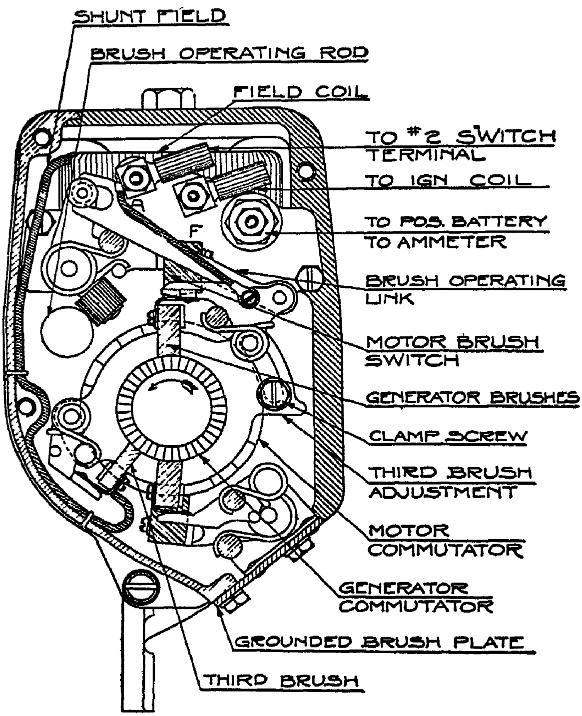


FIG. 610.—Sectional view of Delco motor-generator for Buick "Four" (1923–1924).

engine speeds is not sufficient to overcome that of the storage battery. Consequently, a small amount of current may discharge through the generator winding. At all normal engine speeds, however, the voltage of the

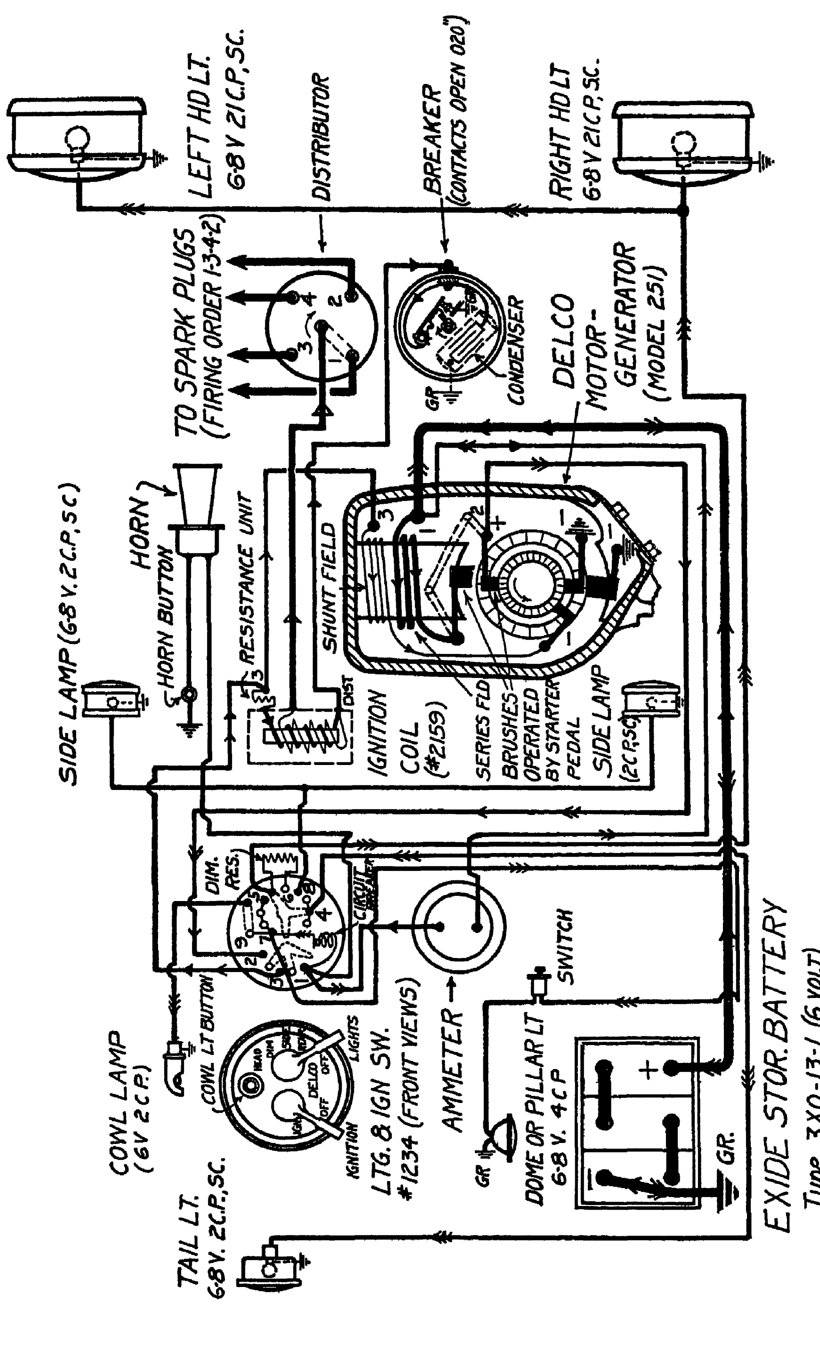


FIG. 611.—Circuit diagram of Delco system on Buick "Four," models 34, 35, 36, 37 and 38 (1923).

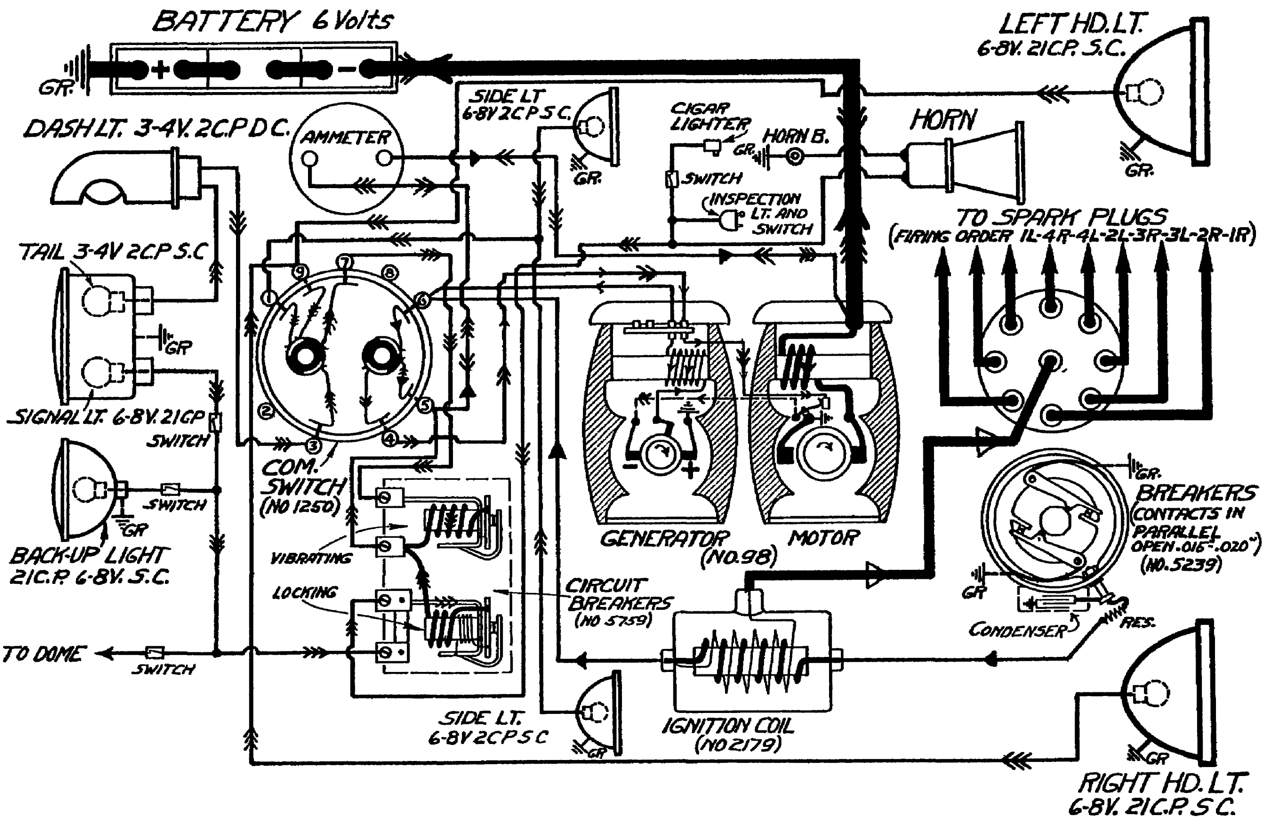


FIG. 612.—Circuit diagram of Delco system on Cadillac "Eight," model V-63 (1924).

generator overcomes that of the storage battery, so that the ammeter will show charge. The maximum charging rate should be approximately 16 amp. at 25 m p.h.

Regulation of the generator output may be controlled by shifting the third brush. Since it shifts, however, in a straight line, if adjustment becomes necessary, care should be taken to "sand-in" the brush, so as to make perfect running contact with the commutator.

2. *Delco Single-unit System on Buick Four* (1923).—The operation of the single-unit Delco system on the Buick Four, 1923 and later models, is similar in many respects to that described for the Buick Six. The principal differences lie in the design of the motor-generator. A cross-sectional view of the unit is shown in Fig. 610, while the wiring of the system is shown in Fig. 611. As may be seen from Figs. 610 and 611, the brush rigging is so designed that, when the starting-motor brush is dropped onto the commutator for cranking, the generator brush is lifted so as to disconnect the generator circuits.

The regulation is through the third-brush principle, the third brush being adjustable so as to increase or decrease the charging rate. When the unit operates as a generator, the maximum charging rate should be 14 to 16 amp. at 1,500 r p.m., or 20 m.p.h. At higher speeds, the charging rate should drop off, due to the characteristics of third-brush regulation.

When running as a starting motor, the unit should crank the engine at approximately 125 r.p.m., drawing 125 to 175 amp. at 5 volts. When running free, it should draw 85 to 90 amp. at 5½ volts and attain a speed of approximately 4,000 r p.m.

This system also employs the usual Delco circuit breaker, which is connected in the lighting circuit and is mounted on the back of the lighting switch. Dimming of the headlights is through a resistance unit also mounted on the switch.

3. *Delco Single-unit System for Cadillac Eight, Model V*-63 (1924).—A complete wiring diagram of the Delco system on the Cadillac Eight, Model V-63, is as shown in Fig. 612. The generator circuits are disconnected through a switch which opens as the motor brush is dropped onto the commutator for cranking.

In other respects, the system operates like that on the Buick Four. Instead of one circuit breaker, however, two are used on the Cadillac, one known as the vibrating type, which is connected in the lighting circuit, and one as the locking type, which is connected in the horn and accessory circuits. The vibrating circuit breaker starts at a discharge of 25 amp. and continues at 10 amp., while the locking circuit breaker locks at 25 amp. and stays locked with a discharge of 1 amp.

When the unit operates as a generator, the ammeter should show charge at approximately 420 r.p.m., the charging rate reaching a maximum of 17 to 19 amp. at 1,500 r.p.m. Regulation is by the third-brush method. When the unit runs as a starting motor, the armature should exert a lock torque of 6 lb.-ft. at 3 volts.

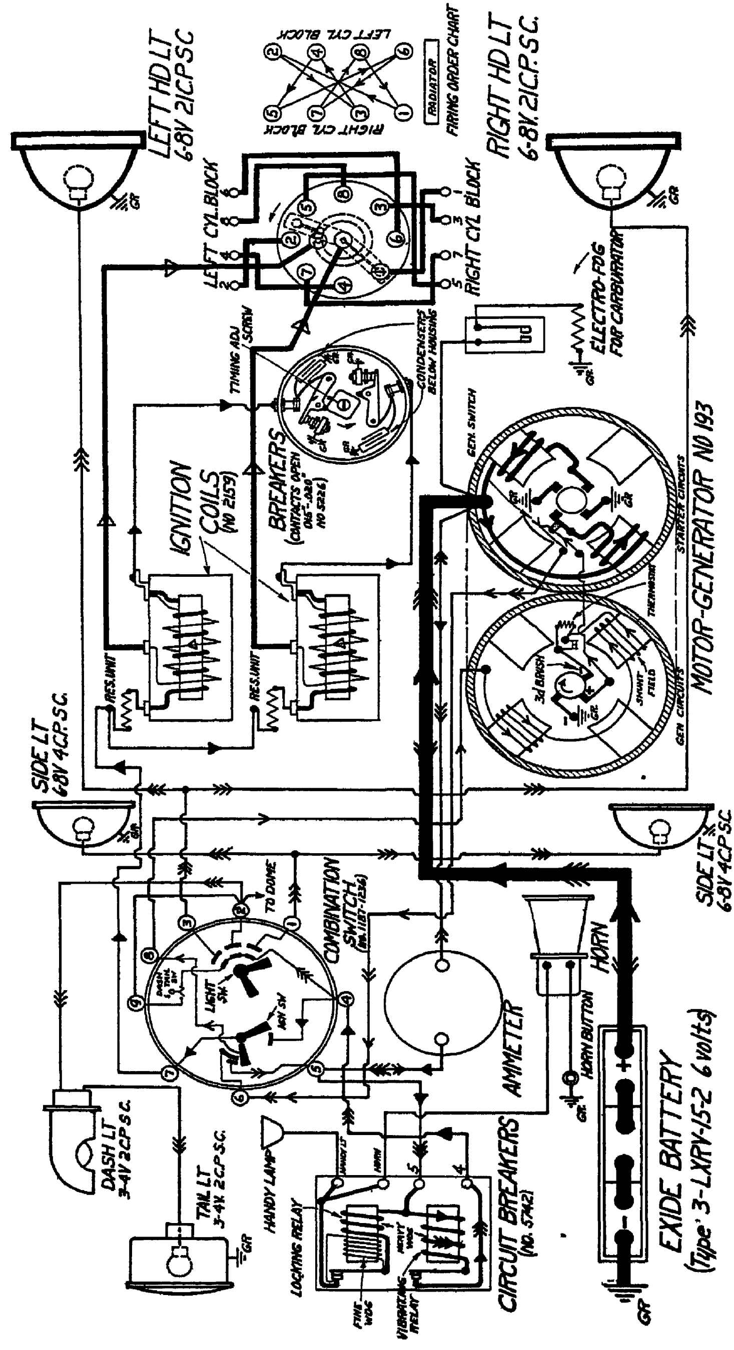


FIG. 613.—Circuit diagram of Delco system on Lincoln "Eight," 1921–1924 models.

4. *Delco Single-unit System for Lincoln Eight* (1921–24).—The Delco starting and lighting unit on the Lincoln Eight is similar in construction and operation to that described for the Cadillac Eight. In fact, it is designed along the same line with a few modifications.

The complete wiring diagram of the system is shown in Fig. 613. One of the important features is the thermostat, which is used to control the maximum operating temperatures of the generator. This operates similar to the thermostat on the Remy generator (Art. 374). As soon as the temperature attains approximately 195 to 205 deg., the thermostat contacts open and cut resistance into the shunt-field circuit, thus reducing the generator output. In other respects, the operation of the system is quite similar to the Cadillac, as may be seen by comparing the circuits.

411. The North-East Electric System.—The North-East single-unit starter-generator, Model G, as used on the Dodge car since 1916, is described in Art. 380. The circuit diagram of the Model G unit is given in Fig. 565, while Fig. 614 shows the complete wiring of the system as installed on the 1918 and 1919 Dodge cars. This wiring corresponds to that of later models, except that in the later types one side of the ignition breaker is grounded so that only one wire runs from the ignition unit to the control switch on the dash. Starting and generating characteristics of the unit are also given in Fig. 566, Sec. XXIII. Regulation is by the third-brush principle.

The North-East Starter-generator, Model D, with Flexible Leads.—The Model D North-East starter generator using flexible leads, as shown in Fig. 615, was used on the Dodge car and several other installations during 1915 and 1916. It differs from the Model G unit principally in the method of regulation. In this unit, a combination current regulator and cutout unit is located in the dynamo housing immediately below the commutator. Circuits of the unit are shown in Fig. 616.

The starter generator operates in conjunction with a 12-volt battery. Two of the flexible leads lead directly to the battery through a battery indicator, as shown in Fig. 616, while the other two leads go to the starting switch. Upon tracing the circuits, it will be found that when the unit operates as a generator, the heavy series winding operates differentially with the shunt winding. This produces reverse-series field regulation in addition to current regulation as provided by the vibrating-type regulator (called "limiting relay"), while as a motor, the two windings operate accumulatively so as to produce a strong magnetic field.

The charging rate of the generator should be approximately 7 amp. maximum. The charging rate can be adjusted by varying the tension of the two springs on the limiting relay. Both springs should have as nearly the same tension as possible so as to have the regulating contacts open at the

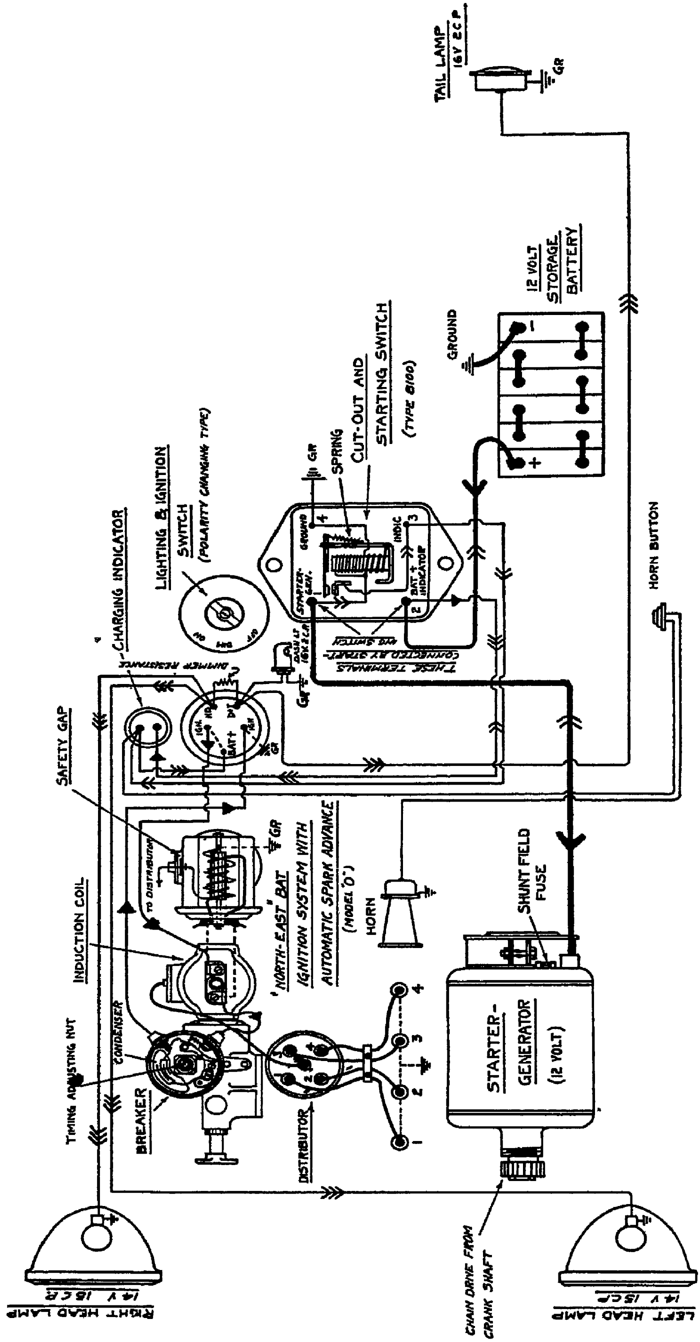


Fig. 614.—Circuit diagram of North East system on Dodge (1918–1919).

same instant. It will be noted that the frame of the relay connects electrically between the two resistance units, so that, should one pair of contacts stick, there would still be regulation by the other pair of regulating points operating through at least one of the resistance units. The regulator points are protected against sparking and pitting by the condenser located between the pole pieces.

Caution.—Since the closing of the starting switch short-circuits the current coil of the regulator during the cranking process, the starting switch should be opened as soon as the engine starts to run under its own power; otherwise, because of the short-circuiting of the current-coil winding by the starting switch (destroying all regulation), there is danger that the excessive voltage generated will cause the burning out of the cutout winding. It would also tend to burn out the lamps if turned on.

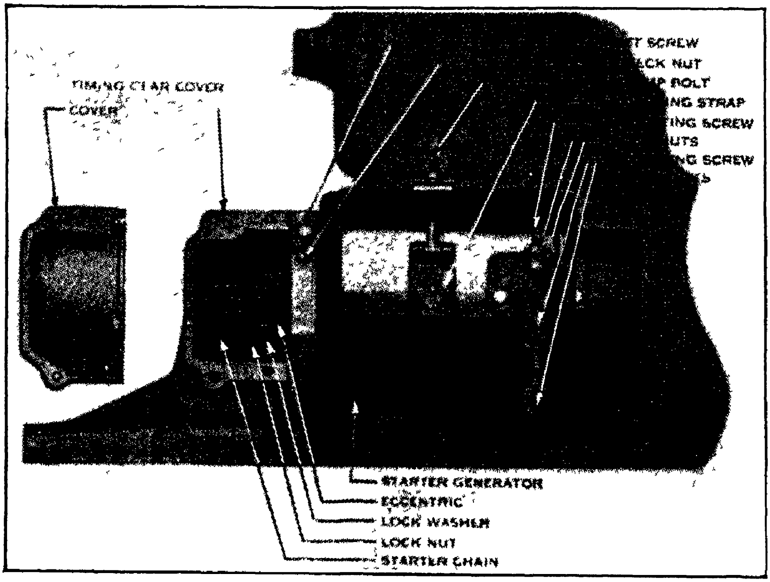


FIG. 617.—Method of adjusting North East starter-generator drive chain on Dodge car.

Adjusting Starter Chain.—In all installations of the North-East single-unit starter generator the drive is through a silent chain from the front end of the crankshaft. In time the chain lengthens, due to wear in each link, so that its tension should be adjusted occasionally. This may be done by shifting the eccentric collar between the sprocket and the front end of the motor generator, as shown in Fig. 617. Shifting the collar in one direction moves the unit away from the engine so as to tighten the chain, while shifting it in the opposite direction loosens it. When in proper adjustment the chain should have about ½ in. up-and-down movement midway between the two sprockets. A properly adjusted chain will run without perceptible noise, but a

chain that is too loose will whip. On the other hand, if it is too tight, a disagreeable hum or squeaking will be noted The chain usually needs adjustment each 3,000 miles of travel.

412. The Simms-Huff System.—The Simms-Huff starter generator, which was used from 1915 to 1921 on the Maxwell, is a starter-generator of the six-pole type. The principal parts of the unit are shown in Fig. 618. In the earlier models it operated in conjunction with the "split" or 6-volt–12-volt type battery (that is, it operated as a starter on 12 volts and as a generator at 6 volts), while in the later models a plain 12-volt battery was used, the voltage being the same for both starting and generating.

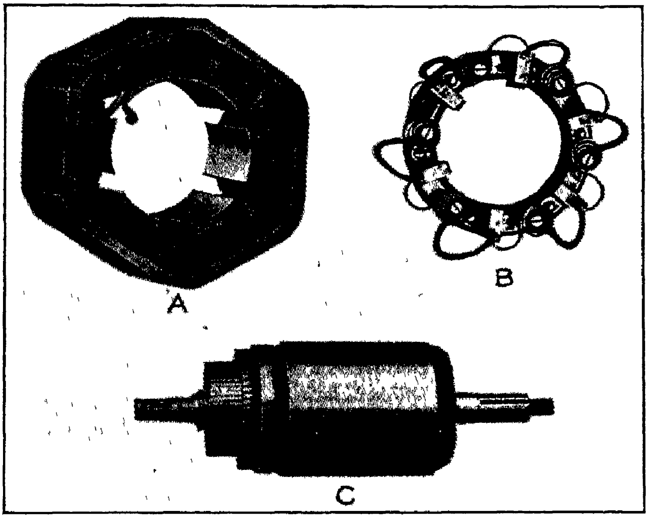


FIG. 618—Parts of Simms-Huff starter-generator. (*A*) Field yoke. (*B*) Brush rigging. (*C*) Armature.

1. *The Simms-Huff System for Maxwell*—1917.—Circuits of the Simms-Huff starting and lighting system as used on the 1917 Maxwell, Model 25, is shown in Fig. 619. As will be found upon tracing the circuits, the two halves of the battery are so connected by the starting switch when in normal running position that they charge in parallel, the circuits being as indicated by the double arrowheads. With this position of the switch, the terminals 4 and 5, and 4 and 1, on the starting switch are connected. In the starting position, terminals 5 and 6, and 1 and 2, are connected, thus throwing the two halves of the battery in series by means of the switch connections.

With the unit operating as a generator, regulation is obtained through reverse-series field winding (the series winding being wound on alternate poles) in combination with a vibrating-type relay mounted in one end of the

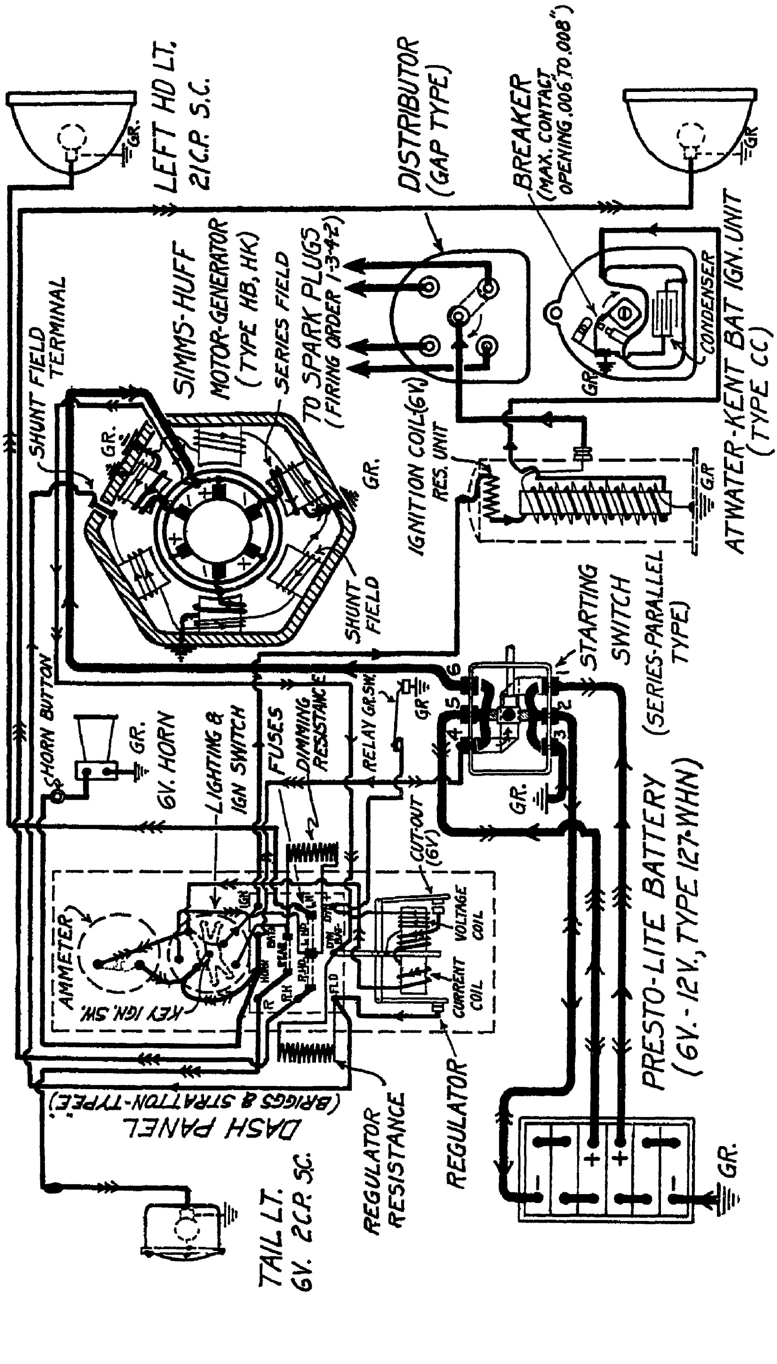


Fig. 619.—Circuit diagram of Simms-Huff starting and lighting system with Atwater-Kent ignition on Maxwell, model 25 (1917).

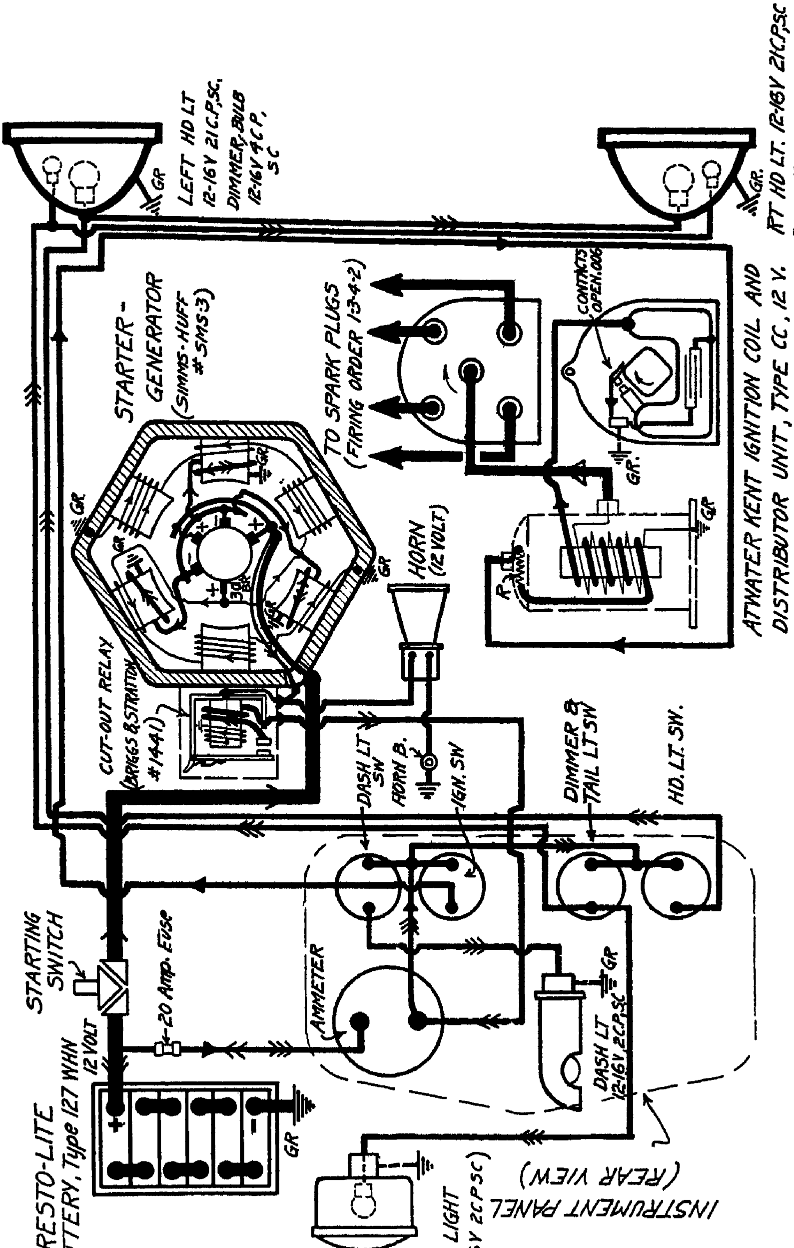


FIG. 620.—Circuit diagram of Simms-Huff starting and lighting system with Atwater-Kent ignition on Maxwell, model 25 (1919–1920).

switch panel. The charging rate is determined by adjusting the regulating-spring tension.

As will be noted, the regulator is of the current type. The charging rate should reach a maximum of 15 amp. at 1,300 r.p.m , or 18 m.p h. Since both halves of the battery charge in parallel, this means that approximately 7½ amp. will be passing through each half of the battery. When operating as a starting motor, the unit should crank the engine at approximately 100 r.p.m., drawing 40 to 60 amp. at 10.5 volts. Its lock torque is approximately 24 lb.-ft. which is attained with 200 to 250 amp. flowing at 9 to 10 volts.

2. *The Simms-Huff System for Maxwell,* 1919 *to* 1920 *Models.*—The wiring for the 1919 to 1920 models of the Maxwell, in which a straight 12-volt battery is used, is shown in Fig. 620. By comparing the circuits of the starter generator with that shown in Fig. 619, it will be noted that a slight change has been made in the arrangement of the brushes and in the method of regulation. In the later model, four main brushes are used in place of six, and a "third," or field, brush has been added to provide third-brush regulation

It will be further noted that the shunt-field winding is separated into two sections each wound on two poles, the circuits being parallel with each other. In addition to the third-brush scheme of regulation there is a slight regulating effect produced by the three poles which carry the series winding, and which act differentially when the unit runs as a generator.

When operating as a generator, the charging rate should reach a maximum of 12 amp. at 1,750 to 1,900 r.p.m., reducing to 10 amp. at 3,000 r.p.m. As a starting motor, it should crank the engine at 150 r.p.m , drawing 50 amp. at 11 volts. Its lock torque is approximately 16 lb.-ft., drawing 200 amp. at 10 volts.

SECTION XXVII

ELECTRICAL ACCESSORIES

413. Types of Horns.—Electric horns used for automotive signaling purposes may be divided into three principal classes as follows: (1) motor-driven, (2) alternating-current or transformer type, and (3) vibrating types. Typical examples of these are shown in Figs. 621*A*, *B*, and *C*, which show the Sparton, the Ford, and the Delco, respectively.

In most cases the horn is located under the hood, where it is protected from the weather, being mounted either on the side of the engine or on the cowl. It is generally operated from the battery

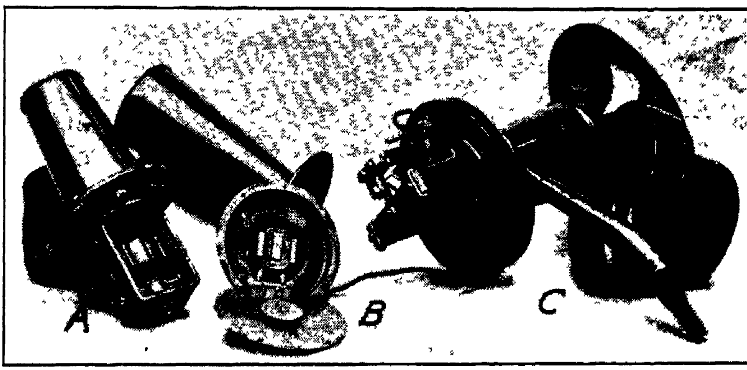


FIG. 621.—Types of horns, showing (*A*) Sparton, (*B*) Ford and (*C*) Delco.

by a pushbutton located within convenient reach of the driver either on the steering wheel, the steering-wheel column, or the left door. Where it is mounted on the door, a special door-type switch is usually required which breaks the horn circuit when the door is open. This means that the horn can be operated only with the door closed and the switch making good contact.

414. The Sparton Motor-type Horn.—The Sparton horn, shown in Fig. 621*A*, is typical of the various motor-driven horns. As will be noted from the circuit diagram shown in Fig. 622, the principal parts comprise a series-wound motor, a sound diaphragm, and the tone projector or horn bell. The motor is so designed that a ratchet-type disc on the rear end of the armature

shaft is made to press against a steel stud or "anvil" mounted on the diaphragm as the disc rotates. This causes the diaphragm to vibrate, producing the warning signal. The motor is series-wound, the circuits being as shown in the Fig. 622.

In order to adjust the tone of the horn, the adjusting screw, which forms also the bearing for the commutator end of the shaft, may be turned to the right or to the left as necessary. Turning it to the right forces the armature toward the diaphragm, compressing the spring which is located between the armature and the supporting bracket, thus decreasing the anvil clearance and increasing the tone, while turning the screw to the left allows the spring to force the armature forward, increasing the clearance between the disc and the diaphragm, thus decreasing the sound intensity.

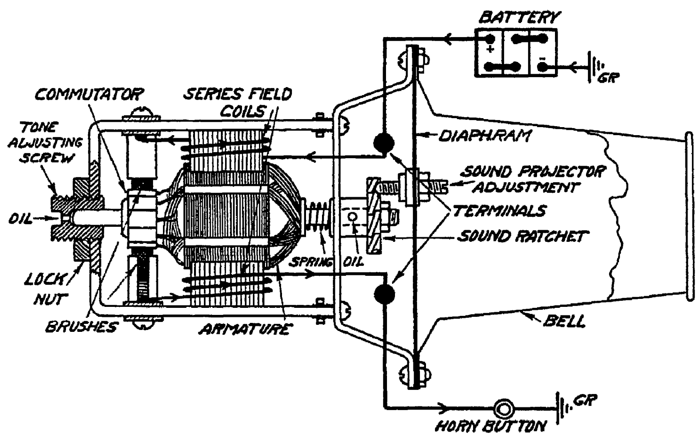


Fig. 622.—Circuit digram of Sparton motor-type horn.

The construction of the armature is similar to that of any D.C. motor, except that it is of small dimensions. The brushes are usually of carbon or copper gauze, and should have sufficient spring tension to make proper running contact at all times.

Care of Horn.—About the only care required of the average motor-driven horn is to make sure that it is properly oiled, that all connections are tight, and that the brushes make proper contact with the commutator. Approximately once every two months the horn motor cover should be removed for inspection, adjustment, and oiling. The motor should then be set in motion and the commutator cleaned by holding a soft cloth moistened with "Three-in-One" oil on the revolving commutator. Also each end of the armature shaft should be lubricated, using two or three drops of high-grade lightweight oil. The same directions apply to all makes of motor-type horns.

415. The Ford Horn—Alternating-current Type.—The Ford horn, Fig. 621*B*, is a specially constructed horn designed to operate on the alternating current produced by the Ford magneto. The general construction and the

circuits of the horn are shown in Fig. 623. The operating element consists of a laminated soft-iron core of the three-legged type, which has a coil wound on the center leg. This coil is connected directly to the magneto when the horn button is pressed. The operation of the horn is as follows: When the magneto current is allowed to pass through the coil winding, an alternating magnetic field is set up through the core, which takes two parallel paths through the core and soft-iron disc, as shown by the dotted lines. Since the coil is excited by alternating current, the magnetism will also alternate in direction, causing the disc to be attracted and repelled successively by the core. This causes the diaphragm to vibrate, producing the sound.

There are no adjustments, other than the tone adjustment, which can be made through the bell of the horn. The intensity of the tone, will, of

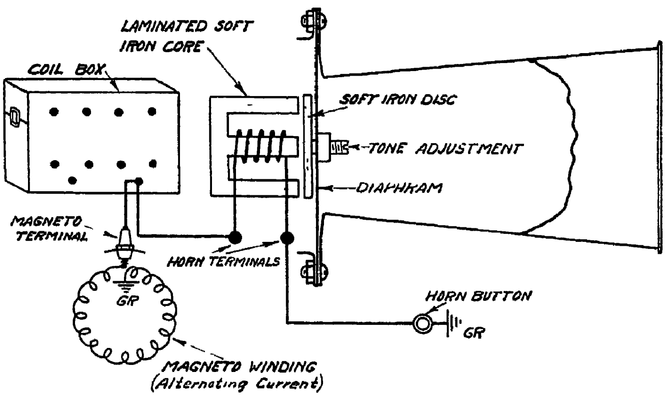


FIG. 623 —Circuits of Ford horn—alternating current type

course, depend upon the magneto voltage produced, which, in turn, depends upon engine speed. The horn can be operated only while the engine is running.

416. The Ford Horn—Vibrating Type.—Figure 624 shows the general construction and the operating principles of the Ford vibrating-type horn as introduced on 1923 cars. The advantage of this horn over the alternating-current type just described, is that it can be operated on direct current from the storage battery. The operating of the horn is similar to that of any electric door bell or buzzer. The principal parts are an electromagnet, a soft-iron armature or vibrator which is attracted by the electromagnet, and a set of vibrator contact points.

When the push button is pressed, the circuit is completed through the electromagnet, causing the armature to be attracted by the magnetism produced in the cores of the electromagnet. The soft-iron armature is mounted on a laminated vibrator spring and has attached to it a hammering pin, the end of which comes close to the steel diaphragm. As the armature approaches the electromagnet, it bears against the spring to which is

attached one of the contact points, thus pulling the points apart and opening the circuit. As soon as the contacts open, the breaking of the circuit causes the electromagnet to demagnetize, allowing the armature to return to its

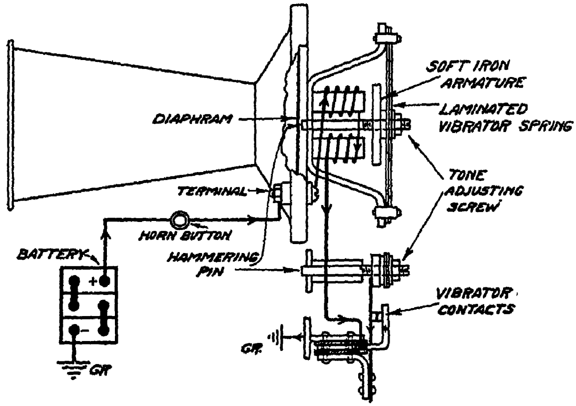


FIG. 624.—Circuits of Ford vibrating-type horn.

original position and reestablishing the circuit through the electromagnet. The result is that the armature vibrates rapidly, causing the diaphragm to give out a loud warning signal, due to the hammering pin striking against it.

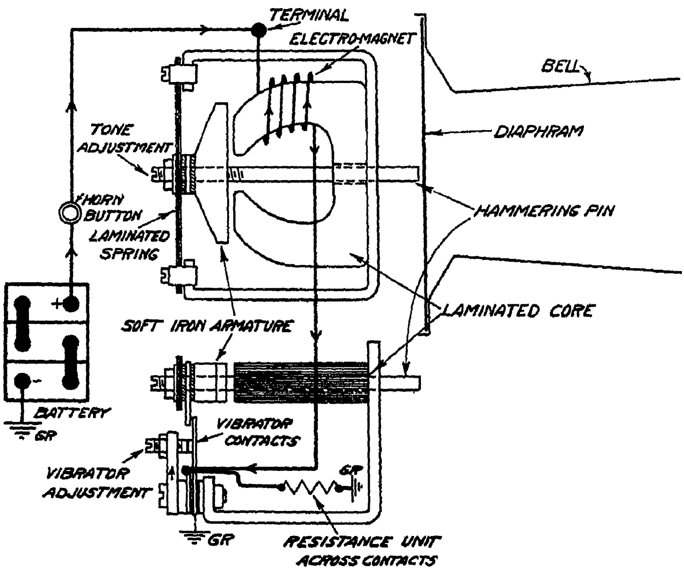


FIG. 625.—Diagram of Delco vibrating-type horn.

Adjustment.—The tone of the horn may be adjusted by loosening the lock-nut on the hammering pin and varying the distance between the end of the pin and the diaphragm. Turning the screw to the right decreases the clear-

ance, while turning it to the left increases the clearance. When the proper tone adjustment is obtained, the locknut should be tightened.

417. The Delco Vibrating-type Horn.—The Delco vibrating-type horn used on the Cadillac is shown in Fig. 621*C*. In principle, it is very similar to that of the Ford vibrating type, as may be seen from the diagram shown in Fig. 625. The hammering pin and the soft-iron armature are attached to a laminated spring similar to the arrangement in the Ford horn. The electromagnet, however, is of different design, the winding being wound in one coil instead of in two, as in the Ford. Also, a resistance unit is connected in parallel with the vibrator contacts, to prevent arcing and pitting When the circuit is interrupted by the opening of the contacts, the current is directed through the resistance unit, which merely reduces the value of

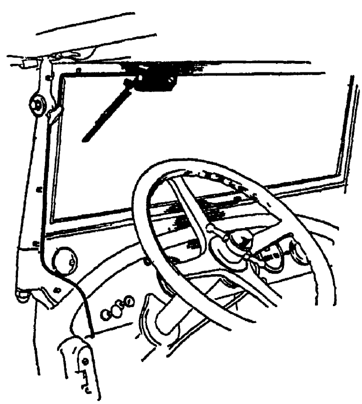


FIG 626 —Installation of typical electric windshield wiper (Stewart).

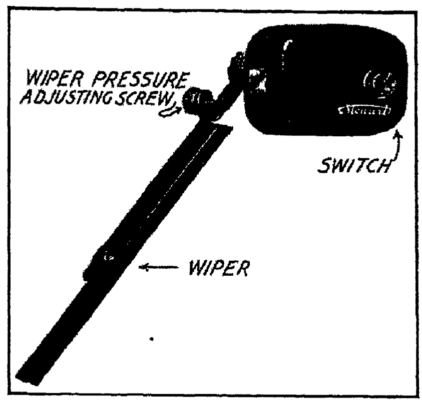


FIG 627 —The Stewart electric windshield wiper

current flowing instead of interrupting it entirely. The warning signal, however, is produced as in the Ford horn—by the hammering pin striking against the steel diaphragm. The tone of the horn may be adjusted by removing the cover, loosening the locknut, and turning the hammering pin adjusting screw to the right or left so as to produce the proper clearance between it and the diaphragm. The horn requires no attention other than to see that the insulated terminal is kept clean and tight.

418. The Electric Windshield Wiper.—An electrical accessory which is becoming widely used is the electric windshield wiper, which operates from the storage battery. It has the advantage over the suction-operated type in that its action is independent of engine operation. In most instances, it is attached to the metal frame at the upper edge of the top windshield glass, as in Fig. 626, being so designed that the rubber wiper oscillates through approximately one-third revolution on the outside of the glass. The switch is also contained on the instrument itself, the unit being connected by a single wire to the generator side of the ammeter, while the other

side of the unit is grounded. In most cases a small shunt-wound motor is used, the oscillating mechanism being driven through a worm drive off the end of the armature shaft.

419. The Stewart Electric Windshield Wiper.—The Stewart electric windshield wiper shown in Fig. 627 is a typical motor-driven unit designed to

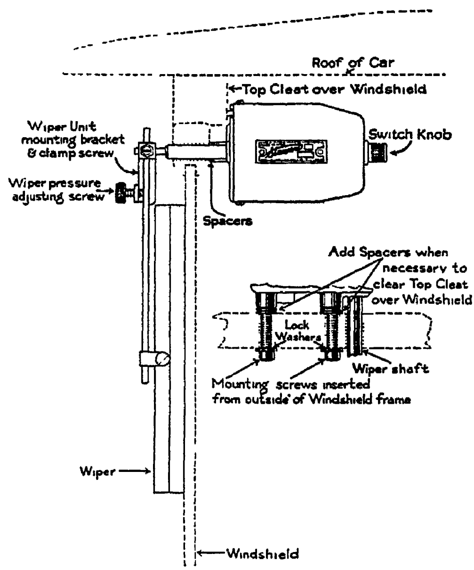


Fig. 628.—Method of mounting Stewart windshield wiper.

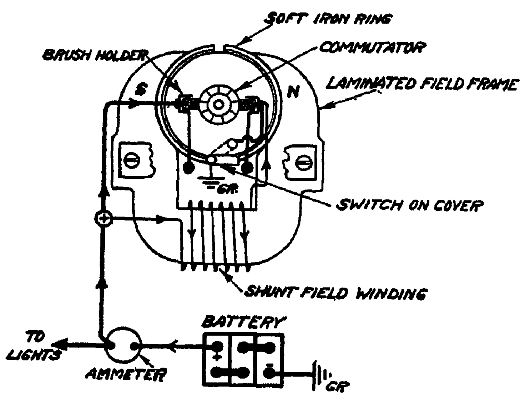


Fig. 629.—Circuit diagram of Stewart electric windshield wiper.

operate on battery voltage. The general location of the unit is shown in Fig. 626, while details of its installation are shown in Fig. 628. As will be noted from a study of the circuit diagram, Fig. 629, the motor is of the shunt-wound, two-pole type, the circuits being as indicated by the arrows. It is

shunt-wound so that the armature will maintain a fairly constant speed, giving a steady motion to the wiper.

A particular feature of this equipment is that the pressure of the wiper against the windshield can be adjusted by turning the wiper pressure adjusting screw, shown in Fig. 627. In adjusting the pressure of the rubber cleaner, it should be borne in mind that the least pressure which will keep the windshield clean of rain or snow is most satisfactory. Should the pressure be too great, the rubber will bend over at right angles, causing, in time, the formation of cracks and the rubber will lose its wiping effect. The wire leading to the unit should be connected to the generator side of the ammeter, that is, so that it shows discharge when the wiper switch is turned on. The current consumption of the unit should not exceed 2 to 2½ amp. while in operation. The bearings should receive one or two drops of light-weight high-grade oil each 2,000 to 5,000 miles of travel, depending upon the extent of use.

SECTION XXVIII

AUTOMOTIVE ELECTRICAL TESTING INSTRUMENTS

420. The Electric Meter.—The importance of the meter on a car is little realized by the car operator. But to the skilled automotive electrician it serves as a guide in the electrical system, as does the compass to an explorer. It is not sufficient to know how to use it as a guide to troubles developing in the rest of the electrical equipment, but the fundamentals of operation and of construction must be understood in order to cope successfully with any troubles occurring in the instrument. It is but a matter of concentrated application of the principles of magnetism and electromagnetism.

421. Kinds and Types of Meters.—The principal kinds of meters used in automotive work are the *voltmeter*, the *millivoltmeter*, the *ammeter*, and the *ampere-hour meter*, all of which may be classified into types according to their construction.

A *voltmeter* may be defined as a device used to measure the electrical pressure applied to a circuit or parts thereof, just as the air gage indicates pressure in a tire

A *millivoltmeter* is a voltmeter so constructed as to measure pressures of extremely small values in thousandths of a volt.

Note—The voltmeter and also the millivoltmeter, have not been used to any extent in automotive work except for testing purposes, which will be explained in Secs XXVIII to XXX inclusive.

An *ammeter* is a measuring instrument used to indicate the rate of flow of current in a circuit, just as a water meter registers the rate of water flow in gallons per minute. The rate of current flow should not be confused with the speed of electricity.

The ammeter is the chief indicating device in the car itself and is also indispensable in service work. It is usually of the type shown in Fig. 7, which is mounted on the instrument board and connected so as to indicate the charge and discharge rate of the battery.

The *ampere-hour meter* might be termed a recording ammeter and is likened to the trip or mileage-registering device used with the speedometer.

The ampere-hour meter finds its chief use in the electric vehicle, although it was used in a few of the early automobile starting and lighting systems, for example, the 1912 Delco, and on some farm-lighting plants.

The chief advantage of the ampere-hour meter is that it provides a convenient means of registering the condition of charge of a battery by indicating the number of ampere-hours which have been discharged by it in comparison to that put into the battery during charge. This information is of particular interest to the electric vehicle operator, since the vehicle depends entirely upon the energy stored in the battery for its cruising range.

In practically all instances the ampere-hour meter is sealed by the manufacturer, who is usually ready either to repair or to replace it should internal trouble arise. The automotive electrician should, therefore, refer all such cases directly to the manufacturer of the instrument rather than attempt repairs and adjustments himself. The same suggestion applies to watt-hour meters.

422. The Plunger-type Meter.—The simplest type of meter for measuring electric current is probably the Plunger type, which is illustrated in Fig. 630.

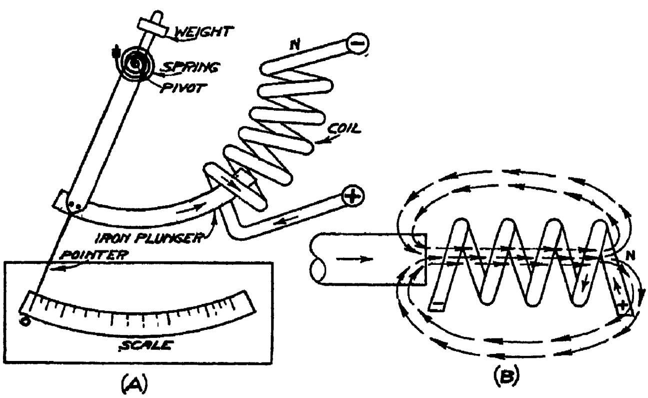


FIG. 630 —Operation of solenoid or plunger type meter

The operation of a meter of this construction is dependent upon the electromagnetic effect which the coil or *solenoid* has upon the iron plunger, which, in turn, causes the needle to be deflected. A current passing through the coil establishes a magnetic polarity which attracts the soft-iron plunger *A* which is supported from and pivoted at *P*. The magnetic attraction for the plunger causes it to move into the coil, thus causing the indicator attached thereto to move across the scale. This magnetic attraction for the plunger is readily seen in Fig. 630*B*. The ease with which the lines of force pass through a magnetic substance, and their tendency to travel the shortest possible path between poles, are the direct causes for the movement into the coil. After the circuit has been broken, so that there is no current flowing through the coil, the spring *S* brings the indicator back to zero position on the scale. The weight *W* is used to counterbalance the indicator and plunger. Because the spring tension increases as the pointer moves across the scale, it will be necessary to calibrate this instrument by sending

current of known value through it. It will be noticed that the movement is less per unit of current increase

The instrument may be made also as a voltmeter, by making the coil of many turns of a fine wire, thus producing a high-resistance winding; whereas as an ammeter the coil consists of a few turns of comparatively coarse wire, thus having a low internal resistance.

Most meters are constructed for either D.C. or A.C. current, but this type may be used for either. Furthermore, the needle will always indicate on the scale, regardless of the polarity of its connecting terminals. These features are made possible because the plunger is made of soft iron and will readily reverse polarity as the coil changes polarity with the alternating current, thus maintaining an attraction.

This type of meter is used principally where a cheap instrument is desired and approximate readings are sufficient. Should trouble arise in a meter of this type, it is usually much cheaper to replace it with a new one

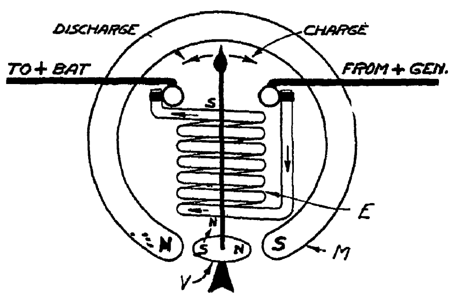


FIG. 631.—Operation of magnetic-vane type ammeter.

423. The Magnetic-vane or Fixed-coil-type Meter.—This type of meter is used mostly for automobile dash mounting. There are several makes on the market which differ only in some mechanical details of construction, the principle of operation of each being practically the same.

The operation of this meter is governed by the law of magnetism: *Like poles repel and unlike poles attract.* A diagram of this type of meter is shown in Fig. 631. After the generator has built up its voltage and the cutout has closed, the current from the generator passes through the coil *E* of the electromagnet in such a direction that it establishes a north pole at the bottom. The small, thin, oval magnetic vane *V*, located between the poles of the permanent magnet *M*, is thereby magnetized, its poles being opposite to those of the magnet.

The operation is then as follows: The north pole established at the bottom of the coil attracts the south pole of the magnetic vane on the left and repels

the north pole on the right, thus causing the vane to turn in a clockwise direction, the movement being in proportion to the magnetic attraction. Since the indicator needle moves with the vane, the position of the needle on the dial can be made to indicate the current value.

The importance of the attraction of the permanent magnet for the armature V is therefore evident. The magnet has a constant force of attraction and repulsion, but the electromagnet has a repelling and attracting force dependent upon the amount of current passing through the coil. Under such conditions the position of the vane will be effected by a difference in the forces of attraction and repulsion; that is, with a low current flowing through the coil there will be a weak pole established by the electromagnet with which to overcome the attraction of the magnet M for the vane and to repel the magnet poles. Consequently, the indicator will move but slightly. When a heavier current is sent through the electromagnet, the poles established are much stronger and, therefore, capable of overcoming the magnetic forces of the magnet to a greater extent, resulting in a greater deflection.

When the current is cut off, the magnetic influence of the permanent magnet on the armature, or vane, returns the indicator to the zero center of the scale.

If a current should be sent through the coil in the opposite direction, as when the car is not operating, and the lights are turned on, there would be a south pole established at the bottom of the coil instead of a north as described above. With this polarity the electromagnet would attract the N pole of the vane on the right and repel the S pole on the left, at the same time repelling the force of attraction of the south pole of the magnet on the right, resulting in a deflection of the needle to the left on the scale.

This type of meter when made for dash use is constructed with a zero center scale, so as to allow for an indication of charge and discharge of the battery. This type of meter has the advantage of being rugged and inexpensive to make, yet quite sensitive. It is not extremely accurate, however, but, even so, makes an excellent meter for the use for which it is intended.

Troubles and Methods of Correcting.—Troubles that may develop in meters of this construction are of a minor nature and may be adjusted if a thorough knowledge of their principles of operation is possessed and good judgment is exercised in the handling of small, delicate apparatus.

Since magnets lose, in time, a certain percentage of their magnetism, this factor should be considered in their application to meters. If a magnet should become weakened in an instrument of this type, the meter would indicate a greater rate of flow of current than was actually passing through it, because the magnet has less force of attraction and repulsion to react with that produced by the electromagnet, thus resulting in a greater deflection for a given amount of current. This is frequently the result of a loose magnet inside the meter, or the meter being mounted loosely in the instrument board, allowing considerable vibration to take place.

This inaccuracy may be corrected by recharging the magnet, which can often be accomplished without removing it from the instrument board.

First, determine the polarity of the magnet in the meter by a magnetic compass, then bring a large permanent magnet, or an electromagnet of the horseshoe type, up to the rear of the dash in such a manner that the unlike poles of the meter magnet and the recharging magnet are together. This will usually be sufficient to charge the small magnet in the meter, especially if pieces of iron are used to bring the poles of the charging magnet nearer the poles of the meter magnet. Rapping the instrument board with the hand while holding the magnet in back of the meter will help, as this makes the molecules vibrate.

It is important that *the north pole of the charging magnet be placed next to the south pole of the meter magnet,* so as to charge it in the proper direction in order to strengthen it. If the polarity should be reversed, the meter would register a still greater amount than it should, due to the weakened meter magnet. Thus, after finishing this procedure, it is advisable to check the results by connecting a portable high-grade ammeter in series with it and comparing the readings of the two meters. With this connection both meters should register the same. If, by checking, it is found that the desired results were not effected, then the ammeter should be taken out and held between the poles of a magnet charger, pieces of iron being used to bring the poles nearer together.

Note—It is usually not worth while to take the meter apart to get the magnet out to recharge it, because of its intricate construction. Should this become necessary, it is usually cheaper and more satisfactory to replace the instrument

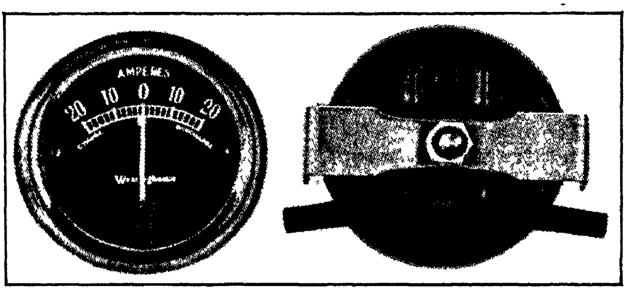


FIG. 632.—Front and rear views of Westinghouse ammeter, type BT.

424. The Westinghouse Dash Ammeter, Type BT.—The Westinghouse meter, type BT, shown in Fig. 632, is a new type of meter which requires no mechanical or electrical connection to the circuit, it depending upon the electromagnetic field set up around a wire carrying a current for its operation. As may be seen in Fig. 632, the wire merely passes through an iron loop at the back of the meter housing. There are no electrical connections whatever. The principle of operation is virtually the same as in the magnetic-vane-type meter.

The general construction and operation of the meter is shown in Fig. 633. The special alloy magnet *M* is so situated in the meter housing that the arch extends out through the rear of the case sufficiently to allow an insulated conductor of the usual size to pass through it. When a current flows through the conductor, the lines of force that are set up around it magnetize the special magnet *M* to a polarity corresponding to the direction of current through the wire.

In Fig. 633, it will be noticed that, with current flowing in the direction indicated, the polarity will be *N* at the top and *S* at the bottom. With such polarity and with the polarity of the permanent magnet *PM* as indicated, there will be a reaction between the magnetic fields of the two magnets similar to that in the fixed-coil type, Fig. 631.

The armature, or magnetic vane, will be attracted in accordance with the polarity, the *N* pole of the alloy magnet *M* attracting the *S* pole of the vane and the *S* pole of the special magnet *M* attracting the *N* pole of the vane, thus causing the pointer attached thereto to move to the right.

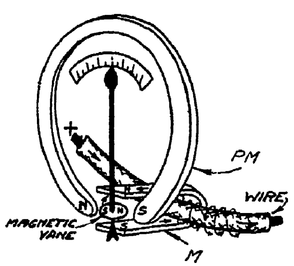


Fig. 633.—Operation of Westinghouse ammeter, type BT.

Should the current be sent through the conductor in the opposite direction to that shown, the magnet *M* would reverse its polarity, whereupon the attraction would be such as to cause the indicator to move to the left. The reading of the meter in either direction is in direct proportion to the current flowing in the conductor and in the magnetic field around it.

It must be remembered that in this type of meter the small magnet *M*, Fig. 633, through which the wire passes, must be of a special magnetic alloy which will retain no magnetism whatever when no current is flowing in the conductor. Should it retain even a slight residual magnetism, there would be a slight deflection of the indicator to one side or the other of zero, depending on which way the current last flowed through the conductor.

Owing to the simple construction, this type of meter is rugged, yet is fairly sensitive and accurate, so that there is little chance of troubles arising. Should repairs become necessary, however, it will usually be found cheaper to replace the instrument.

425. The C.O.D. Current Indicator.—The C.O.D. current indicator, Fig. 634, so called since it has three readings, "Charge," "Off," and "Discharge," was designed to operate in battery-charging circuits where the current may rise at times to high values beyond the capacity of the ordinary dash-type ammeter. Its principal use has been with certain types of single-unit systems, such as certain models of the North East and the Dyneto starter-generators, where the wires leading from the starter-generator to the battery are required to carry both the starting and the

charging current. The C.O.D. indicator merely indicates the direction of the current passing through the circuit, but does not register its value in amperes.

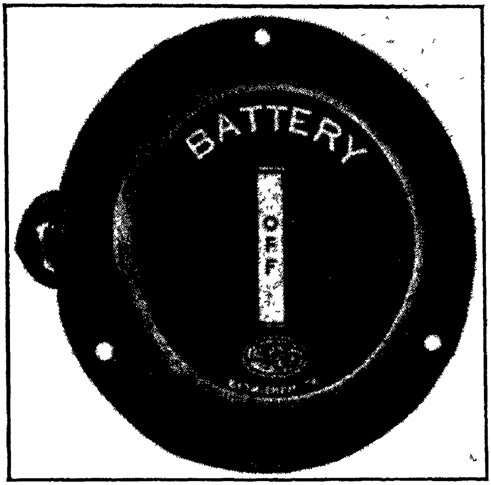


FIG 634 —Typical C O.D. current indicator.

Typical construction of the C.O.D. indicator is shown in Fig. 635. It is made up of a stationary solenoid and a small permanent magnet which is free to swing on a pivot as shown. Passing a current through the coil from *A* to *B* establishes a magnetic

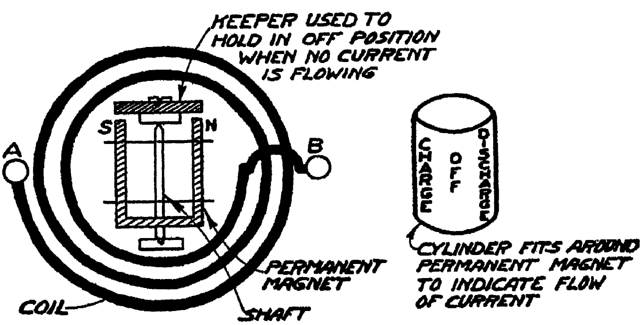


FIG. 635 —Operation of C O.D. current indicator.

field through it with the *N* pole to the front (toward the reader), that is, the magnetic lines of force travel out the front around the outside into the rear and toward the front again. The field of the solenoid reacts with that of the permanent magnet in such a

manner as to cause the magnetic lines of the solenoid to pass through the magnet in the same direction as the lines of the magnet itself, or from south, S, to north, N. This causes the permanent magnet to swing on its pivot, so that the S pole of the magnet is near the S pole of the solenoid, while the N pole is near the N pole of the coil and indicates "discharge." The position of the magnet is indicated to the driver by a paper cylinder which surrounds and rotates with it, Fig. 635, causing the words "Charge," "Off," and "Discharge" to appear before the window. If a current is sent through the coil from B to A, the solenoid polarity would be reversed, with a subsequent movement of the magnet to the right, indicating "Charge."

It sometimes happens that the polarity of the small permanent magnet is reversed, so that the indicator reads "Charge" when it should read "Discharge." This condition can be determined by turning the lights on when the engine is not running and noting the indication. Such a trouble may be corrected by reversing the leads on the back or by reversing the magnetism in the magnet.

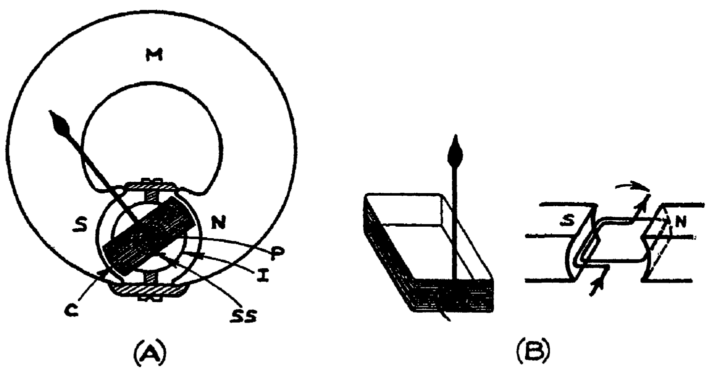


FIG. 636.—Construction and operation of D'Arsonval or moving coil type meter.

426. The D'Arsonval or "Moving-coil-type" Meter.—The D'Arsonval or "moving-coil-type" meter is the construction generally found in the more expensive meters used for automotive electrical testing. It is much more accurate than the types previously described; however, it is very delicate and requires much skill in its manufacture.

The general construction of the "moving-coil-type" meter is shown in Fig. 636. As the name indicates, the coil C is the moving element. It consists of comparatively fine wire wound on a

light aluminum frame, which is pivoted and free to rotate between the poles of the permanent magnet *M*. At each end of the coil, and surrounding the pivot *P*, very light spiral springs *SS* are mounted in such a manner that, when connected to the bearing supports, one spring counteracts the tension of the other. Under these conditions the coil assembly and pointer will rest in a position where the springs are equally opposed. This establishes the zero position on the scale, which may be located either at the center or at the extreme left of the dial, as the use of the meter may require. The springs also serve to conduct current to and from the coil.

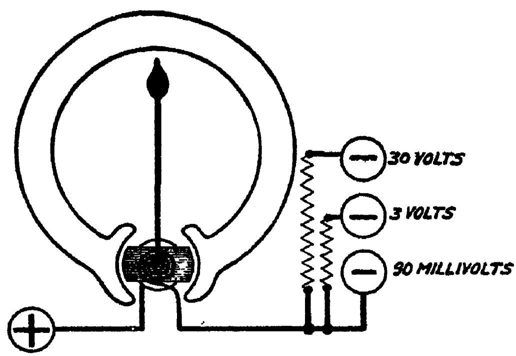


FIG 637 —Method of connecting D'Arsonval or moving coil meter with different resistances to measure different voltages.

Principle of Operation.—The operation of the meter depends upon the reaction of the magnetic field produced by the coil and that of the permanent magnet. The principle of operation is quite similar to that of a simple electric motor. When a current is sent through the coil, the coil assembly has a tendency to rotate on its axis, due to the repulsion of the two fields, as illustrated in Fig. 636*B*, thus causing the needle to move across the scale in a corresponding direction.

The magnetic core *I* is inserted in the coil in a fixed position to reduce the reluctance (magnetic resistance) of the magnetic circuit from pole to pole, and also to provide a uniform magnetic field throughout the area of the poles. The springs are made of sufficient diameter, length, and of proper gage material so that there is no appreciable increase in difference of tension between the two springs as the indicator moves across the scale; otherwise, there would be a difference in the calibrations on the scale—smaller deflection for unit increases in current as full scale reading is approached.

Since the winding of the movable coil has comparatively low resistance and is sensitive to considerable movement to produce needle deflection with very little current passing through it, it can be used either to indicate voltage,

provided suitable resistance is connected in series with it, or it can be used to indicate current should it be connected in parallel with a shunt having suitable resistance. As a voltmeter, it can be used to register different voltages by connecting separate resistances of proper value in series with the movable coil, while as an ammeter, different shunts, having different resistances, may be used, depending upon the amount of current to be measured. The method of using it as a voltmeter having different ranges is shown in Fig. 637, while Fig. 638 shows its connection with a shunt for measuring current. It should be remembered that as a voltmeter the instrument is connected across the circuit, or across that part of the circuit in which the voltage drop is to be determined, while as an ammeter the instrument is connected in the circuit so that the current must pass through it in parallel with the shunt.

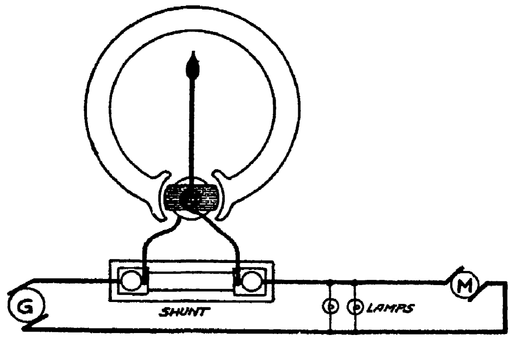


FIG. 638.—Method of connecting voltmeter to measure line current or voltage drop across part of circuit.

427. Principles of the Volt-ammeter for Automotive Electrical Testing.—For the testing of automotive electrical equipment, such as the generator, the starting motor, lighting circuits, etc., voltage ranges of 0 to 90 millivolts, 0 to 3 volts, and 0 to 30 volts are generally needed. And if the instrument is to be used in general garage work, a range of 0 to 150 volts is often needed to measure the voltage of direct-current power lines. For measuring current, the common scale readings desired are 0 to 3, 0 to 30, and 0 to 300. The first two are needed for testing generator and lighting circuits and the last for starting current. Thus, if the same movable coil is to be used with different resistances as a voltmeter, or with different shunts as an ammeter, the resistances of each must be worked out accurately.

In several makes of prominent instruments designed for automotive electrical testing, the resistance of the movable coil winding is 6.428 ohms, while the current required to cause full scale deflection is only

0.014 amp. This means that, according to Ohm's law, in which the volts = amperes × ohms ($E = I \times R$), the voltage necessary to produce full scale deflection will be 0 014 × 6 428, or 0.090 volts, which may be referred to as 90 millivolts, since a *millivolt* equals one-thousandth of a volt. Thus, with the voltage, current, and resistance characteristics of the movable coil determined, various resistances and shunts may be readily constructed to obtain voltage and current scale readings as desired. Such an instrument is therefore known as a volt-ammeter, since it can be used either as a voltmeter or as an ammeter, although not necessarily at the same time.

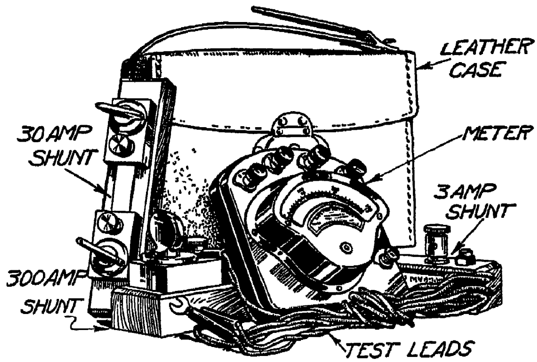


FIG 639.—The Weston volt-ammeter, model 280.

428. The Weston, Model 280, Volt-ammeter.—The Weston Model 280 volt-ammeter, as shown in Fig. 639, is designed expressly for automotive electrical testing. It is usually furnished with three shunts, giving a range as an ammeter of 0 to 3, 0 to 30,

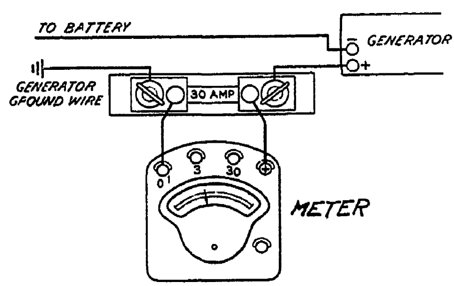


FIG. 640.—Method of connecting Weston, model 280, volt-ammeter with external shunt for measuring generator charging rate.

or 0 to 300. When used as a voltmeter it generally has a range of 0 to 90 millivolts, 0 to 3 volts, and 0 to 30 volts. As an ammeter the meter must be connected with the proper shunt, as in Fig. 640, while as a voltmeter the instrument is connected across the source of voltage, as in Fig. 641, the voltage readings being obtained by

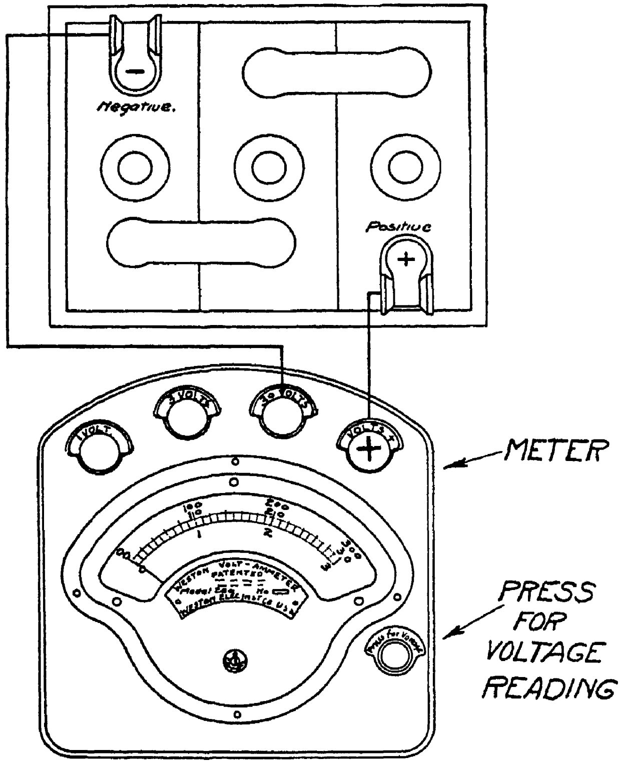


FIG. 641.—Method of connecting Weston volt-ammeter, model 280, for voltage readings up to 30 volts.

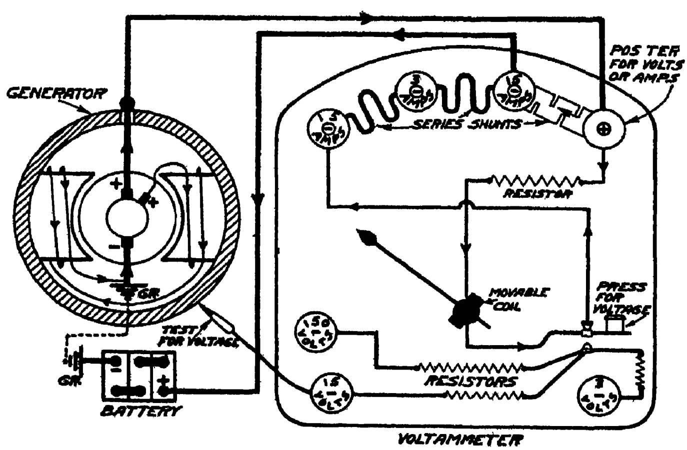


FIG. 642.—Circuits of Weston, model 280, volt-ammeter with internal shunts and separate voltmeter terminals.

the pressing of the button at the right of the scale. This applies to meters furnished with the shunts connected externally.

The meter is also furnished with separate voltmeter terminals, as shown in Fig. 642. In this design the smaller shunts are included in the instrument, the circuits being as shown. The readings as a voltmeter are obtained by pressing a button, as in the other model.

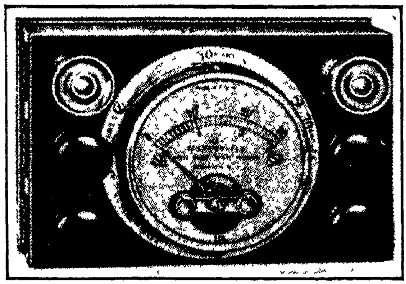


FIG 643.—Hoyt rotary type meter for automotive electrical testing.

429. The Hoyt Rotary Meter.—The Hoyt rotary meter, designed for automotive electrical testing, shown in Fig. 643, is so constructed that, to obtain different voltage and ammeter scale readings, the meter itself may be rotated so as to form electrical connections with the different connecting terminals. The internal circuits are as shown in Fig. 644. Two shunts are included, namely, the 3- and the 30-amp., while the large shunt,

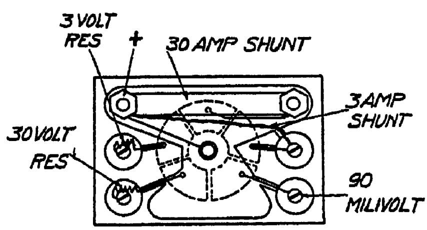


FIG. 644.—Internal terminal connections of Hoyt rotary meter. Bottom view.

which may be either 300 or 500, is connected externally between the terminals marked "+" and "90 mil-v.," with the meter set on the 90-millivolt position. The particular advantage of this type of testing instrument is that it is small and compact and that it is somewhat "fool-proof," because two mistakes must be made, namely, placing the meter in the wrong position and connecting the test leads to the wrong terminals, before injury

will occur to the instrument. Assume, for example, that it is required to measure approximately 30 volts. The meter is then rotated until the terminal comes in contact with the segments connected to the proper spool of resistance wire, which, in turn, is connected to the 30-volt bar and post. However, if 30 volts were passed through the proper bar and post, but the meter was accidentally over the 3-volt segment, no current would flow and no injury would be done to the instrument.

430. The Jewell Volt-ammeter, Pattern No. 37.—In the Jewell meter, shown in Fig. 645, two separate meters are incorporated in the same case, one functioning as a voltmeter and the other as an ammeter. The shunts are also included in the case, so that

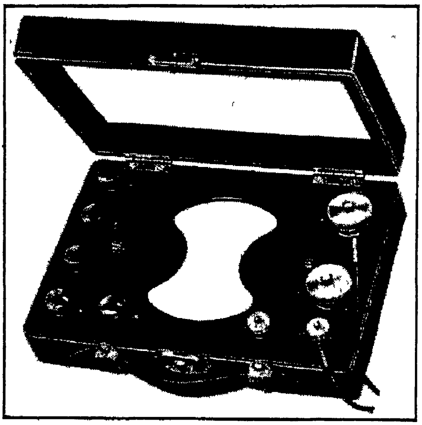


FIG. 645.—Jewell meter, pattern No. 37, for automotive electrical testing.

all connections are made to the meter itself. As a voltmeter, a range of 0 to 0.3, 0 to 3, 0 to 30, and 0 to 150 may be obtained, while as an ammeter it has a range of 0 to 3.5, 0 to 35, and 0 to 350. Such a meter can be used as an ammeter and as a voltmeter at the same time. This is desirable in many instances in automotive electrical testing.

431. Care of Electrical Testing Instruments.—Since the mechanism of the electric meter is more or less delicate, it is highly important that the meter should be handled carefully and not allowed to receive serious jolts, such as dropping or striking with tools. Also, care should be taken in selecting the meter connections, so that the scale used will always be greater

than the maximum value of the current or voltage to be measured. Should the meter be connected so as to read beyond the range intended, usually the instrument will be burned out. Should the needle become bent or not register zero, it can usually be made to do so by turning the zero adjusting screw to the right or to the left in accordance with the correction desired. In the more expensive meters, such as the Weston, the Hoyt, and the Jewell, should injury occur to the meter itself, it is generally recommended that the meter be sent directly to the manufacturer for repairs.

SECTION XXIX

ARMATURE AND FIELD TESTING

432. Indications of Generator Armature Troubles.—Some of the more common indications of generator armature troubles are as follows: (1) generator not charging; (2) generator charging intermittently; (3) low charging rate at high speeds; and (4) excessive sparking of the brushes. These indications are usually obtained with the generator on the car by observing the dash ammeter or by inspecting the commutator with the engine running at a speed above that at which charging should begin. To determine definitely the nature of the trouble, the generator should be taken off and the armature removed for special testing. The same procedure applies to the motor.

433. Diagnosing Armature and Field Troubles by Motorizing the Generator.—In many cases the trouble in the generator may be located by running it as a motor from a storage battery having the same rated voltage, and noting its operation. If the discharge through the generator is measured by an ammeter, much can be learned by comparing the current consumption, the armature speed, and the action of the ammeter needle with those for a good generator of the same type. The generator should rotate as a motor in the same direction as it is to be driven as a generator, and should rotate at a given speed and should draw a constant current from the battery. Should the armature fail to rotate as a motor, it indicates either armature or field trouble, and each should be tested separately. If the armature rotates at an irregular speed and the ammeter needle fluctuates considerably as the armature rotates, it indicates defective armature winding which may be shorted, open, or grounded. If the armature tends to stop, or will not start, with brushes on certain segments, it indicates that the armature is open-circuited. In any event, should the armature not rotate at proper speed, draw the proper amount of current, and rotate in the proper direction, both the field and armature windings should be tested separately.

434. Armature Troubles.—Armature troubles may be divided into two classes, namely, electrical and mechanical, depending upon the nature of the trouble. The electrical troubles include those of the windings, while mechanical troubles comprise those pertaining to the core, the shaft, the commutator, brushes and the bearings.

1. *Electrical Troubles.*—An armature may become defective electrically due to the armature coil windings becoming (*a*) open-circuited, (*b*) short-circuited, or (*c*) grounded. An *open-circuited coil* is one in which the circuit through the coil is open, due to either a broken wire or its connection to the commutator bar becoming unsoldered. A *short-circuited armature coil* is one in which the insulation has become defective, allowing the various turns of the same armature coil to make metal contact with one another, so as to short-circuit them in whole or part, or they may become short-circuited due to moisture. *A grounded armature coil* is one in which an electrical circuit is established between the coil and the core on which it is wound.

2. *Mechanical Troubles.*—The more common of the mechanical troubles include, (*a*) improper alignment of the armature, due to worn bearings, which, in turn, may cause rubbing of the pole pieces and shorting of the laminations; (*b*) commutator out of round, preventing improper seating of the brushes; and (*c*) bent armature shaft, which causes the armature to run out of balance. The latter may be due to improper alignment of the generator, due to the driving chain or belt being too tight.

435. Testing Armature for Defective Armature Windings.—As mentioned above, the armature may not generate properly, due to the winding becoming (1) short-circuited, (2) open-circuited, or (3) grounded. This is caused usually by over-loading and eventually heating of the windings and commutator. Similar troubles may also arise from mechanical injury, such as dropping or striking the armature, rubbing of armature against pole pieces, etc. If the trouble is on the outside, such as the leads becoming unsoldered from the commutator bars, the armature can usually be repaired without rewinding. If the trouble is internal, however, the armature must be either completely rewound or replaced. If the armature has been in service, the defective armature coils can usually be located by noting the condition of the commutator segments. Defective armature coils are indicated by certain commutator bars being more pitted than others, because, when in operation, excessive sparking occurs at the bars which connect to the defective coils.

1. *To Test Armature for Short-circuited Coil.*—One of the most rugged methods of testing an armature for short-circuited windings is to test it on a special armature-testing transformer, Fig. 646, commonly termed a "growler," which operates on alternating current. With the current

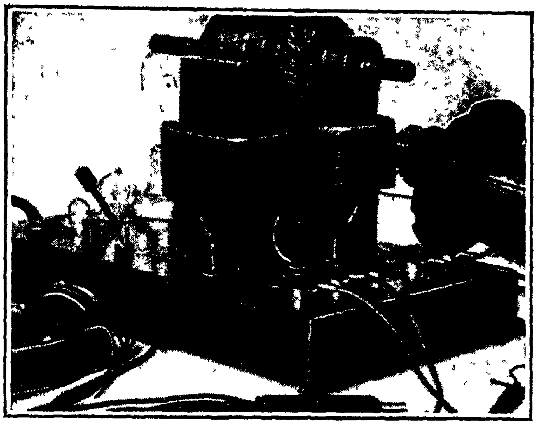


Fig. 646—Typical "growler" for testing armature windings (Jiffy)

turned "on," and turning the armature slowly on the poles of the "growler," pass a thin strip of iron or steel, for example, a broken piece of hacksaw blade, lightly over the top side of the armature, as shown in Fig 647, and note if it tends to vibrate over any particular coil If it does, that coil is short-circuited.

Fig 647.—Testing armature on growler for short-circuited coils.

The armature may also be tested for short-circuited coils by measuring the voltage drop between commutator bars, using a low-reading voltmeter (0–.1 or 0–3 range) and one dry cell connected as in Fig. 648. All coils should register the same voltage drop. In the case of a short-circuited coil,

however, the voltmeter needle will drop back toward zero. The short-circuit millivolt test, using 0– 1 scale, should only be made after the armature is tested and found to be free of open-circuited coils.

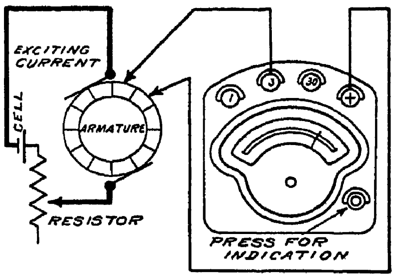


Fig. 648.—Connections for using Weston, model 280, volt-ammeter for testing armature.

2. *To Test Armature for Open-circuited Coil.*—Either the "growler" or the low-reading voltmeter may be used for locating an open-circuited armature coil. In using the "growler," rotate the armature on the poles, as in (1), and test the induced voltage set up between adjacent commutator bars either with a 3- to 6-volt test lamp or an A.C. voltmeter. The test lamp is usually sufficient, the varying brilliancy of filament indicating a change in voltage. The A.C. meter, however, is more accurate. With the test points held in the same relative position on the commutator, the lamp should glow with the same brilliancy on all adjacent commutator bars. If

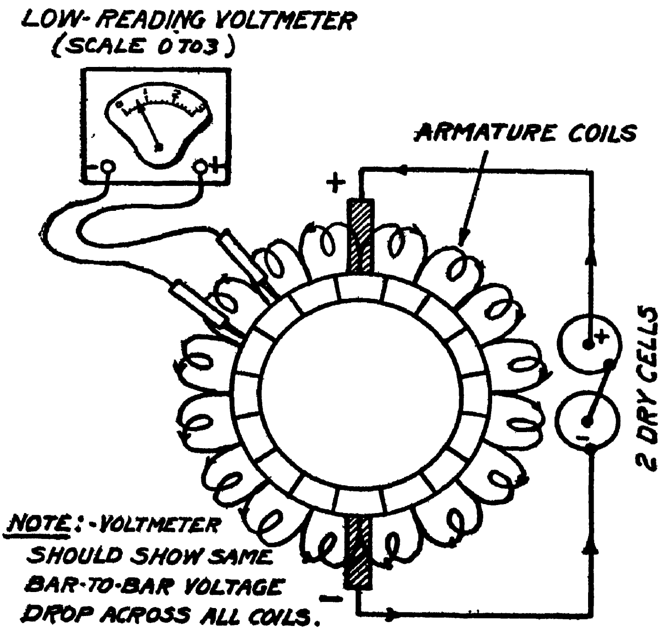


Fig. 649.—Method of testing armature for open-circuited coil using low-reading voltmeter.

it goes out on certain commutator bars, or the A.C. meter needle drops toward zero, yet the armature coil does not test "shorted" by test (1), the coil is unquestionably open circuited.

In testing for open-circuited coils using a low-reading voltmeter, proceed the same as in test (1) for shorted coil, but using 0 to 3-volt scale voltmeter and two dry cells, as shown in Fig. 649. In the case of an open coil, the voltmeter will not register until its test points span the open coil.

Another simple way of locating an open-circuited coil in case the open is at the commutator, is to test from bar to bar around the commutator with fairly heavy leads from a well-charged storage battery, allowing the battery to send a high discharge for a moment through the connecting armature coils. The appearance of an arc or curl of smoke at any of the commutator-bar coil connections indicates a coil not properly soldered.

Note.—In case an armature is remedied by resoldering the coil connections, the commutator should be trued up in a lathe and polished, since it will usually be found out of round.

3. *To Test Armature for Grounded Coils.*—An armature may be tested for grounded coils by testing with a 110-volt test lamp from commutator to core, as in Fig. 650. The lamp should light only if the winding is grounded.

Note—In case of double-wound armatures, such as the Delco or the Wagner single-unit types, a test should be made between commutators to determine if one winding is grounded upon the other

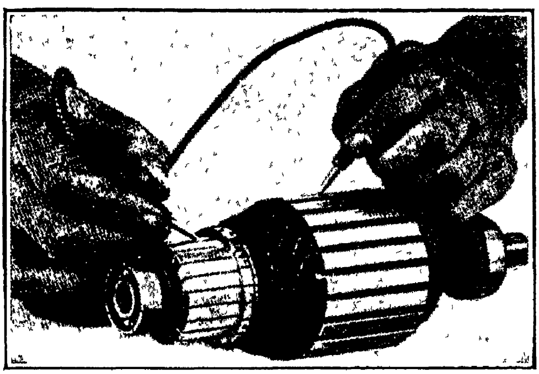


FIG. 650—Testing armature with 110-volt test lamp for grounded winding

436. Mechanical Armature Troubles.

—The effect of the various mechanical troubles and the usual remedy for each are as follows:

1. *Commutator Out of Round.*—This is indicated by the failure of generator to charge at high speeds, due to poor brush contact. A light cut should be taken off the commutator in a lathe and the commutator polished with No. 00 sandpaper.

2. *Worn Armature Shaft Bearings.*—This has the same effect as a commutator out of round, that is, the generator may generate only at low speeds, due to the poor brush contact at high speed. If the bearings become

so badly worn that the armature rubs on the pole pieces, the laminations may become shorted and the armature may be ruined beyond repair. Shorted laminations are indicated by the heating of the armature core when it is rotated in a strong magnetic field. Worn bearings are usually due to the lack of lubrication or excessive strain on the bearing caused by the driving chain or belt being too tight, or by the armature being out of mechanical balance.

3. *Bent Armature Shaft*—This may be due to operating with the driving chain or belt too tight. It may also be caused by the armature striking the pole piece, due to improper bearing alignment, causing a springing of the shaft. The effect is the same as a commutator out of round. The only remedy in most cases is a new armature.

4. *Wrong Lead of Armature Coils, or Brushes in Wrong Position*—Should the wrong lead be used in connecting the armature coils to the commutator, the effect will be the same as the placing of the brushes in the wrong position. Both will result in excessive sparking of the brushes and low voltage and current output. In practice, wrong brush position may be due to the brush rigging working loose and turning around the commutator on account of the dragging of the brushes. On the other hand, the brush-end plate and rigging may be assembled in the wrong position, say 90 deg. off, in case the generator is of the round type and has been taken apart.

5. *Wrong Type of Armature Used.*—Should the armature be improperly wound, for example, the winding is for a four-pole field frame when a two-pole type is required, or *vice versa*, no current will be generated. The remedy is to install a new armature of proper design.

437. Field Troubles.—The common troubles which may occur in the field winding of the generator or motor include: (1) open circuits, (2) short circuits, and (3) grounds. The indication, the method of testing, and the usual remedy in each case are as follows:

1. *Open Connection in Shunt Field.*—The generator may be tested for an open-field circuit without removing the armature by first insulating the brushes from the commutator, and testing across the two ends of the shunt-field winding with a storage battery or dry cell, as shown in Fig. 651. If the circuit is complete, a spark should be obtained upon removing one of the test points, even when the low voltage of one dry cell is used in testing.

2. *Short-circuited Field Coils.*—A short-circuited field coil may be determined by measuring with a low-reading ammeter the current which the coil draws (disconnected from the brushes) at a certain voltage, say 6 volts, in comparison with that which a good coil will draw. The short-circuited coil will have less resistance and, consequently, will draw more current at the same voltage, than a good coil of similar dimensions. Another method that may be used in locating the shorted coil is to test each pole piece for magnetic pull, using a piece of soft iron. The pull of each pole piece should be approximately the same.

The field coil may become shorted due either to defective insulation, permitting metallic contact of the wires, or to moisture, in which cases the trouble may be remedied by either reinsulating the wires or baking them in an oven (not over 250 deg. F.) to drive out the moisture. Coils that have become short-circuited through over-heating, charring the insulation, must be replaced.

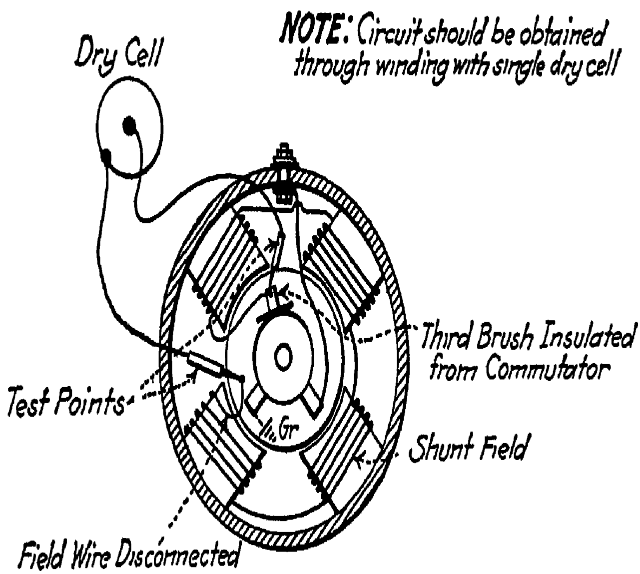


FIG. 651 —Testing shunt field for open circuit, showing Ford generator

3. *Grounded Field Coil*—The field winding may be tested for a ground by disconnecting the winding from the brushes and removing all permanent grounds. The test is then made from one end of the field winding to the generator frame with a 110-volt test lamp. The lamp will not glow unless the winding is grounded.

SECTION XXX

GENERATOR AND STARTING-MOTOR TROUBLES AND REMEDIES

438. Generator Does Not Charge the Battery.—If the generator does not charge the battery as indicated by the ammeter on the dash when the engine is running above the speed at which the cutout should close, corresponding usually to a driving speed of 7 to 10 m.p.h. on high gear, the trouble may be due to one or more of the following:

1. The generator not building up a voltage.
2. The cutout not closing properly.
3. Corroded or loose battery terminals.
4. Defective battery.
5. Ammeter burned out or terminals disconnected.
6. Generator driving clutch or belt slipping.
7. Improper wiring of system.

Test.—To determine if the generator is generating a voltage, test across the main generator brushes or terminals with either a low-voltage test lamp (6- or 12-volt) or a D.C. voltmeter (0–30 range) with the engine running at moderate speed. Any voltage produced by the generator will be indicated by a glowing of the test-lamp filament or by a voltage reading on the voltmeter. Excessive voltage indicates an open connection in the charging circuit.

If the generator is producing sufficient voltage for charging the battery but still the battery is not being charged as indicated by the ammeter on the dash, further tests covering items 2 and 7 should be made. After the wiring has been examined to make sure that all connections are clean and tight and that the battery terminals are free of corrosion, if the ammeter still does not indicate charge with engine running at 800 to 1,000 r.p.m., but will indicate discharge if the lights are turned on, it is evident that an open occurs in the charging circuit between the generator brushes and the ammeter—probably in the cutout.

The cutout contacts may not be closing due to an open or poor connection in the voltage-coil circuit, dirty contacts, contact-arm point sticking, or spring tension being too stiff. If the trouble is caused by the cutout contacts not closing properly, the ammeter should show charge when the cutout is

closed by hand, or when its *generator* and *battery* terminals are short-circuited by a short wire or by a pair of pliers, as in Fig. 652. In case the cutout is found at fault, or the charging circuit is open at any other point, the fault should be remedied at once, since continued operation of the car may result in complete discharge of the battery and burning out of the lamps, cutout, and generator, due to the improper voltage regulation of the generator. The ignition system, if of the battery type, may also be seriously injured.

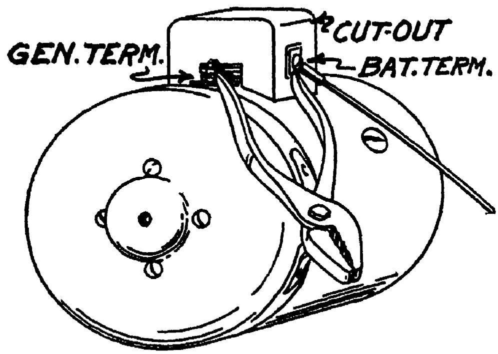


FIG. 652.—Method of short-circuiting cut-out with pliers on Ford generator.

439. Conditions Which Prevent Generator from Generating Proper Voltage and Current.—Common conditions which prevent the generator from generating sufficient voltage and current to charge the battery, including their causes and remedies, are as follows:

1. *Dirty Commutator or Excessive Lubrication, Causing Flooding of the Commutator with Oil.*—Oil is a poor conductor; therefore it prevents proper brush contact on the commutator. It may also cause sticking of the brushes in their holders. The generator will usually charge upon pressing in on the brushes. This condition may be remedied by cleaning the commutator and the brushes with a cloth moistened with gasoline. If the commutator is rough, polish it with No. 00 sandpaper. Generator bearings should receive only three to five drops of light high-grade oil each 500 to 1,000 miles of travel.

2. *High Mica.*—This is caused by the copper segments of the commutator wearing away faster than the mica, due to friction with the carbon brushes. It is indicated by the spasmodic charging of the generator, accompanied by excessive sparking of the commutator and brushes. Excessive sparking, in turn, will cause rapid wearing of the brushes and pitting of the commutator segments. The armature should be removed, the mica undercut, and the segments polished with No. 00 sandpaper. *Never use emery cloth.*

If the commutator is badly pitted or out of round, it should first be trued by taking a light cut off it in a lathe.

3. *Brushes Worn, Broken, or Sticking in the Holder.*—Worn or broken brushes should be replaced with new ones of the size and quality recommended by the manufacturers of the generator. Each brush should move freely in the holder and have proper spring tension. When new brushes are installed, they should be "sanded in," to make a perfect fit with the commutator.

4. *Weak or Broken Brush Spring.*—Weak spring tension may result from the brushes being worn short, or it may be due to the loss of spring temper as a result of over-heating. Over-heated or broken brush springs must be replaced and the tension adjusted to that recommended by the manufacturer, usually 1¼ to 1½ lb. The method of measuring the spring tension was shown in Fig. 572.

5. *Open Connection in Shunt Field.*—This may be due to a blown fuse, loose or dirty connections, broken field wire, or, in a generator with vibrating-type regulators, the regulator contacts not closing properly.

6. *Short-circuited or Grounded Field Coil.*

7. *Short-circuited, Open-circuited, or Grounded Armature Coils.*

8. *Commutator Out of Round.*

9. *Heavy Short across Main Brushes.*—This will prevent entirely the generator from building up a voltage. It may be due to an insulated brush lead making metallic contact with the generator frame or brush cover, or to defective insulation on generator terminal or wire, causing grounding of the current, since one side of the generator is usually permanently grounded.

10. *Worn Armature Shaft Bearings.*—(See Art. 436.)

11. *Bent Armature Shaft.*—(See Art. 436.)

12. *Brushes in Wrong Position.*—(See Art. 436.)

13. *Field Coils Opposed, on Two-pole Generator.*—This may occur more readily in generators of the box-type frame upon the installation of new field coils. The remedy is to reverse one of the coils.

14. *Reversed Direction of Armature Rotation, or Reversed Shunt-field Connections.*—In case the armature rotation is to be reversed, the shunt-field connections to the brushes should also be reversed. Otherwise the field excitation will oppose the residual magnetism and the generator will not build up a voltage.

Note.—When testing a generator, it should be driven in the same direction as it is driven on the car. *Any automobile generator will run as a motor in the same direction of rotation as it must be driven in order to generate.*

15. *No Residual Magnetism.*—This may have been caused by a repair man testing through the field winding with alternating current. The field frame may be given residual magnetism by closing the cutout by hand, allowing the battery to discharge through the generator field windings for a few seconds.

16. *Wrong Type of Armature Used.*—(See Art. 436.)

17. *Driving Clutch or Belt Slipping.*—A slipping driving clutch or belt is indicated by low charging rate at all speeds. A slipping clutch of the over-running type can usually be repaired by renewing the worn part—the outer ring. In a belt-driven generator, provision is usually made for tightening the belt by raising the generator.

440. Procedure in Undercutting High Mica.—High mica on the commutator is caused by the carbon brushes wearing down the copper segments faster than the mica. This trouble may be remedied by undercutting the mica about $1/64$ to $1/32$ in. below the surface of the segments. This may be done by a special undercutting machine, or by hand, using an improvised saw made

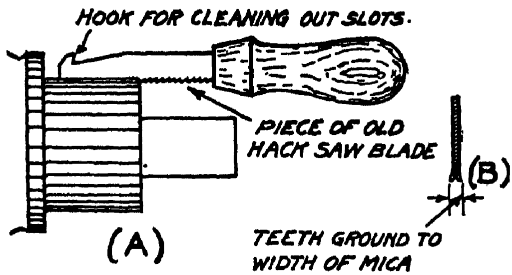


FIG. 653.—Improvised tool for undercutting mica in commutator.

from an old hacksaw blade, as shown in Fig. 653. The sides of the teeth should be ground off so that the width of the cut is slightly less than the width of the mica. To start the cut, draw the saw backwards at the edge of the commutator, then gradually lengthen the cut to the full width of the commutator. The tool should be guided properly, so as to avoid unnecessary scratching of the commutator surface. When the undercutting

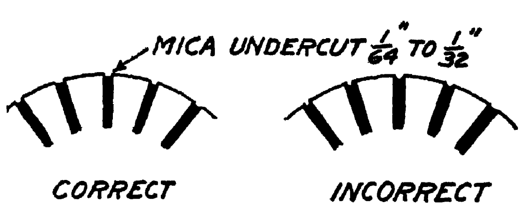


FIG. 654.—Correct and incorrect way of undercutting mica.

is completed, the commutator should be polished with No. 00 sandpaper. In case the segments show signs of previous pitting, it may also be advisable to take a light cut of the commutator in a lathe to insure that it is perfectly round. When the mica is properly undercut, it should appear as in Fig. 654*A*, and not as shown in Fig. 654*B*. If the commutator is turned down, the brushes should also be sanded in to insure perfect fit.

441. To Adjust the Cutout.—The cutout spring should be adjusted so that the contacts will close when the voltage of the generator has reached from 6½ to 7 volts in a 6-volt system, or from 13 to 14 volts in a 12-volt system. These voltages are usually reached, causing the cutout to close, at a car speed of from 8 to 10 m.p.h. on direct drive. The cutout should be adjusted to open when the voltage of the generator falls below that of the battery; in fact, it should open when the discharge current, as indicated by the ammeter, is between zero and 2 amp., preferably as near zero as possible, to prevent flashing of the contact points. The car speed at which the cutout opens should be 2 to 3 m.p.h. below the closing speed.

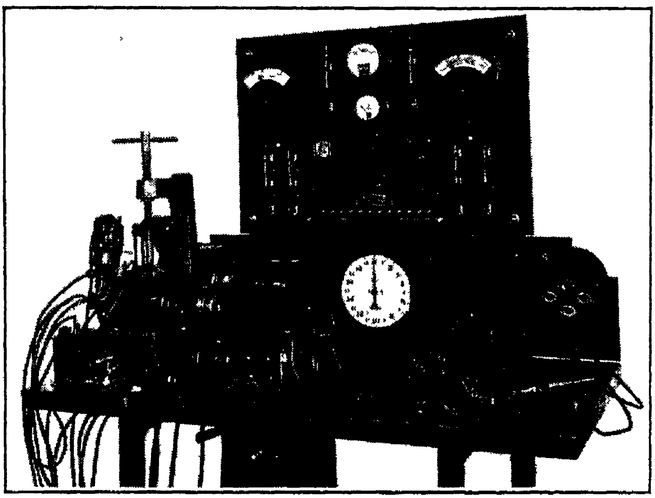


FIG. 655.—Wiendenhoff test bench for making running tests on generators, starting motors, magnetos, etc.

The most accurate way of adjusting the cutout to close at the proper voltage is to check it with a low-reading voltmeter connected across the generator terminals or the voltage-coil terminals of the cutout. If a suitable voltmeter is not available, the spring tension (for a 6-volt cutout) should be adjusted so that the contacts will just close when test leads from five dry cells, or from one dry cell in series with a 6-volt storage battery (giving approximately 7.5 volts), are connected across the voltage coil of the cutout, (see Fig. 504*A*, Sec. XX). The contacts should close firmly at this voltage but remain open when tested with 6-volt leads. For a 12-volt system, the cutout spring should be adjusted to allow the contacts to close at 14 volts, or the voltage of seven storage cells, but should remain open when tested with 12 volts.

442. Effect of Battery Installed with Reversed Polarity.—A trouble which sometimes arises in service station work is the installation of a battery with reversed polarity, so that, when the engine is operating, the ammeter indicates discharge instead of charge. At first thought it may be assumed that the battery is charging in the wrong direction. But this is usually not the case, for if a battery is installed with terminals connected reversed with respect to the generator polarity, for example, the positive terminal is grounded instead of the negative, as intended by the car manufacturer, the generator in most cases will also reverse its polarity, so that the positive brush connects to the positive battery terminal and the negative brush to the negative terminal, respectively, when the cutout closes. A remedy for this condition would be either to reverse the connections on the back of the ammeter or to change the battery to its proper connections. In some instances the design and the adjustment of the cutout may be such that the generator will not reverse itself automatically when the engine is started. This condition is indicated by the rapid closing and opening of the cutout accompanied by the jumping of the ammeter needle from one side to the other. To change the generator polarity, the engine should be stopped and the cutout points closed momentarily with the fingers, to allow the battery to discharge through the generator windings. This will reverse the residual magnetism in the pole pieces, causing the generator polarity to be in accordance with that of the battery. *It is usually impossible to charge a battery in the wrong direction by the generator on the car.*

443. Methods of Adjusting Generator Regulation.—The charging rate of various types of generators may be adjusted in accordance with the method of regulation as follows:

1. *Governor regulation* controlling either armature speed or resistance in shunt-field circuit. The spring tension should be either increased or decreased.

2. *Differential Field Winding.*—The charging rate cannot be changed without changing the proportion of shunt- and series-field winding.

3. *Vibrating-type Regulators.*—The charging rate may be increased or decreased by slightly increasing or decreasing, respectively, the spring tension on the regulator points. In the current-type regulator, the charging rate will be constant above the regulating speed regardless of the condition of charge of the battery. In the voltage-type regulator, the charging rate

will be greatest when the battery is discharged and will decrease as the battery becomes charged.

4. *Third-brush Regulation.*—The charging rate may be increased by shifting the third brush (small field brush) slightly in the direction of normal armature rotation, and decreased by shifting it in the opposite direction. The maximum charging rate should be obtained at 25 to 30 m.p.h. Above this speed, the charging rate should decrease with an increase in engine speed. The third brush must be sanded in to make a perfect fit with commutator to insure proper regulation.

Should it become necessary to test the performance of a generator at different speeds, a test bench equipped with a variable-speed motor for driving it, such as shown in Fig. 655, will be found of great assistance. In most cases these benches are equipped with a speed indicator or tachometer, including a voltmeter and an ammeter for measuring the voltage and current while the generator is in operation.

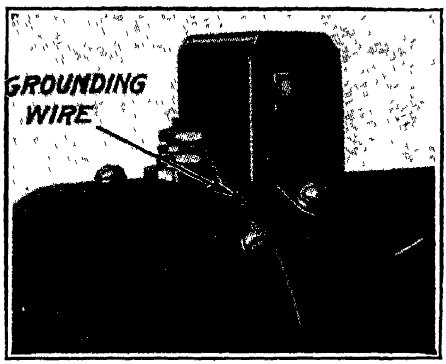


FIG. 656.—Method of short-circuiting (grounding) generator when operating car without storage battery (Ford).

444. Procedure to Operate Car without Storage Battery.—In many instances where magneto ignition is provided, it may be desirable to operate an automobile engine with the storage battery disconnected. In this event, the generator should be protected against building up a voltage, otherwise serious injury may result to the generator and cutout windings. This applies to all generators of the current-regulated type, including the reverse-series, the current-regulator, and the third-brush types. The following are effective methods of preventing the generator from building up a voltage:

1. Remove the shunt-field fuse.
2. Short-circuit the main brushes by grounding the insulated generator terminal as in Fig. 656.

3. Remove the third brush. (This does not apply to the Dyneto used on the Packard Eight.)

4. Disconnect the shunt-field wire on the generator or the regulator.

Note.—Be sure to put the generator back into charging condition when the battery is installed.

445. Starting-motor Troubles.—Starting-motor troubles are indicated either by failure of the starting motor to start or insufficient cranking power when the starting switch or pedal is depressed. Since the successful operation of the motor is dependent upon the condition of the battery, the starting switch, the cables, and the connections, these also should be examined thoroughly in case starting troubles occur. The general test procedure for the various typical cases that may arise are as follows:

1. *If the starting motor fails to start*, turn on headlights and try the starter. If the lights burn but do not dim down when the starting switch or pedal is fully depressed, look for an open at some point in the starting circuit that is preventing the current from flowing through the motor. The trouble may be due to one or more of the following causes:

(*a*) Starting switch not making proper contact.

(*b*) Loose or dirty terminal on starting switch.

(*c*) Rusty, corroded, or loose ground connection from battery to frame of car.

(*d*) Corroded battery terminals.

(*e*) Loose or dirty starting motor-terminals.

(*f*) Dirty or glazed commutator.

(*g*) Brushes not bearing on commutator. This, in turn, may be due to brush being worn too short, brush sticking in holder, weak or broken spring, or brush lead too short.

(*h*) Brush material of too high resistance.

(*i*) Open-circuited armature coil at commutator.

(*j*) Open-circuited field coils.

2. *If the lights dim down when the starting switch is fully depressed yet the motor shows no signs of life*, the starting system should be examined for short circuits. These may occur either in the internal or in the external motor circuits as follows:

(*a*) Short-circuited or grounded armature coils.

(*b*) Short-circuited or grounded field coils.

(*c*) Short-circuited or grounded brush leads.

(*d*) Defective brush-holder insulation.

(*e*) Defective starting-switch insulation.

(*f*) Defective starting-cable insulation, causing ground to car frame, between starting switch and motor.

(g) Armature caught on pole pieces due to defective bearings, bent armature shaft, or spread armature coils.

(h) Stiff starting-motor bearings in combination with weak battery.

3. *If the starting motor starts but is unable to crank the engine at the proper speed*, this may be due to either trouble in the starting system or to the engine not being free to turn. The latter condition may be determined by turning the engine over by hand.

If the engine will not turn over, look for engine trouble as follows:

(a) Bad engine bearings, causing seizing of crankshaft or camshaft.

(b) Piston seized in cylinder, due to improper lubrication.

(c) Engine stiff, due to low temperatures in cold weather.

(d) New bearings not worn in.

(e) Bendix drive stuck in flywheel.

If the engine is free to turn, look for troubles in the starting system as follows:

(a) Battery discharged.

(b) Corroded battery terminals.

(c) Battery of insufficient capacity, due to its being too small, being worn out, being badly sulphated, or having defective internal insulation or low electrolyte. *Remedy.*—Replace with fully charged battery of proper capacity.

(d) Partial opening in battery between plates and post or post and connector, due to poor lead burning.

(e) Poor contact or connections at starting switch.

(f) Poor contact between battery grounding cable and car frame.

(g) Battery cable connection eaten too small, due to action of electrolyte.

(h) Short circuit between starting cable and car frame.

(i) Loose or dirty starting-motor terminals.

(j) Dirty commutator or excessive lubrication.

(k) Brushes not all bearing on commutator.

(l) Brushes stuck in brush holders.

(m) Brush material of too high resistance.

(n) Brushes in wrong position.

(o) Open, short-circuited, or grounded armature coils.

(p) Short-circuited or grounded field coils.

(q) Short-circuited or grounded brush leads.

(r) Defective brush-holder insulation.

(s) Defective armature bearings.

(t) Dragging of armature on pole pieces.

(u) Binding of motor bearings, due to improper alignment, lack of lubrication, or motor-end housing studs not tightened properly.

(v) Starting-motor pinion meshing too tightly with flywheel gear.

(w) Over-running clutch slipping.

Note.—Undoubtedly the most satisfactory method of testing the cranking ability of any starting motor is the torque test, as explained in Art 382.

4. *If the starting motor spins but does not crank the engine*, this condition may be due to the following:

than the maximum value of the current or voltage to be measured. Should the meter be connected so as to read beyond the range intended, usually the instrument will be burned out. Should the needle become bent or not register zero, it can usually be made to do so by turning the zero adjusting screw to the right or to the left in accordance with the correction desired. In the more expensive meters, such as the Weston, the Hoyt, and the Jewell, should injury occur to the meter itself, it is generally recommended that the meter be sent directly to the manufacturer for repairs.

APPENDIX

QUESTIONS

SECTION I

FUNDAMENTALS OF ELECTRICITY

1. Describe briefly the three forms of electricity.

2. Name the five effects of electric current, illustrating each by means of a sketch.

3. Name three methods of generating electricity, explaining briefly the principles of each.

4. What is meant by electrical resistance?

5. Upon what factors does the electrical resistance of a direct current circuit depend?

6. (*a*) What is meant by *electrical conductivity?* (*b*) Name five substances used as electrical conductors on the automobile.

7. Give definitions for the following electrical units: (*a*) Volt, (*b*) Ohm, (*c*) Ampere, and (*d*) Watt.

8. (*a*) State Ohm's Law. (*b*) Explain how the resistance of a circuit may be determined if the applied voltage and the current are known.

9. Explain what effect a rise in temperature has on the resistance of the following: (*a*) Metal conductors, (*b*) Carbon, (*c*) Insulating Materials, (*d*) Electrolytic solutions.

10. Calculate the horsepower required to drive a battery charging generator delivering 40 amp. at 50 volts.

11. (*a*) Calculate the combined resistance of the three lamps connected in parallel, as shown in Fig. 10, if their resistances are 10, 5 and 2 ohms, respectively. (*b*) What would be the total current draw of the three lamps if connected across a 6 volt battery.

12. Explain the chief differences between a primary and a secondary electric cell.

13. (*a*) What are the voltage and current capacity of a good No. 6 ignition type dry cell? (*b*) How may the cell condition be determined?

14. Explain how to calculate the voltage and current capacity of dry cells when connected: (*a*) in series, (*b*) in parallel, and (*c*) in multiple-series.

SECTION II

MAGNETISM AND ELECTROMAGNETISM

1. Explain the difference between magnetic and non-magnetic metals, giving examples of each.

2. (*a*) What is meant by magnetic poles? (*b*) What is the action between like poles and also between unlike poles when brought together?

3. Explain briefly the molecular theory of magnetism.

4. What is meant by the following: (*a*) *magnetic permeability*, (*b*) *saturation point*, (*c*) *residual magnetism*, and (*d*) *retentivity?*

5. Explain the relation between the direction of flow of a current in a wire and the magnetic field produced around it.

6. What factors control the strength of an electromagnet?

7. Describe two methods of determining the magnetic polarity of an electromagnet.

8. (*a*) What is meant by an induced current? (*b*) How is it produced?

9. Explain the right-hand three-finger rule for determining the direction of an induced current.

10. What is the function of the commutator on the simple direct-current generator shown in Fig. 42?

11. (*a*) What causes the armature coil to rotate in the simple direct-current motor shown in Fig. 44? (*b*) What factors govern its direction of rotation?

12. Describe briefly four methods of determining the polarity of two live wires.

SECTION III

IGNITION REQUIREMENTS OF AUTOMOTIVE ENGINES

1. Define the term *gas-engine cycle.*

2. Explain the principal differences between the four-cycle and the two-cycle type of engine.

3. (*a*) What is the function of the carburetor? (*b*) What constitutes a *too rich* and a *too lean* a mixture?

4. What is meant by *period of flame propagation* and how is it influenced by the shape of the combustion chamber?

5. Why is spark advance and retard necessary on automotive engines?

6. (*a*) Explain how it is possible for some two-cylinder engines to have sparks occur at the spark plugs in both cylinders at the same instant. (*b*) What precaution is necessary in timing the ignition on such an engine?

7. In a four-cycle V-type motor-cycle engine, such as shown in Fig. 62, explain how to determine the angles passed through by the crank between successive explosions in the front and rear cylinders, if the angle between cylinders is known.

8. (*a*) What governs the firing order in a multiple-cylinder engine? (*b*) How may the firing order in a four or six-cylinder engine be determined?
9. Explain how to determine the firing order of an eight-cylinder V-type engine having all cranks in the same plane.
10. (*a*) How does the crankshaft for the Cadillac Eight engine, Model V-63, differ from previous models? (*b*) What advantages are claimed for it?
11. Explain how to determine the firing order of a twelve-cylinder V-type engine.
12. What are the angles passed through by the crankshaft between successive explosions in the Liberty "twelve" aircraft engine? Why?

SECTION IV

ELEMENTS OF MAKE-AND-BREAK AND JUMP-SPARK IGNITION

1. Name the component parts of the make-and-break ignition system, explaining the function of each.
2. Explain the action of the make-and-break coil in producing an ignition spark.
3. How does the induction coil of a jump-spark ignition system differ in construction and operation from the make-and-break type coil?
4. Explain the function and action of the condenser used in the jump-spark ignition system.
5. Explain the difference between open- and closed-circuit type breakers
6. (*a*) Of what materials are the breaker contact points composed and why? (*b*) What is the usual maximum contact opening on closed-circuit type breakers?
7. What is the difference between the function of the breaker and that of the timer?
8. (*a*) Explain the operation of the vibrating-type ignition coil. (*b*) Why is no condenser used in the timer?
9. What is the purpose of a master vibrator and how is it connected in a vibrating coil ignition system such as the Ford?
10. What voltages are usually required to jump the normal spark-plug gap under 75 lb. compression?
11. What is the purpose of the safety gap?
12. What effect has compression pressures on spark-gap resistance?

SECTION V

SPARK PLUGS

1. Name the component parts of a typical spark plug explaining the purpose of each.
2. (*a*) What precautions, as to the design and type, should be taken when installing a new spark plug. (*b*) What effect has spark plug location on its performance?
3. Describe the three types of spark plug screw-threads, explaining the advantages and disadvantages of each.

4. What effect does a change in temperature have on the electrical conductivity of spark plug porcelains?

5. (*a*) Of what materials are spark plug porcelains made? (*b*) Why is firing of the porcelain necessary?

6. Explain the advantages and disadvantages of the cone- and petticoat-type porcelains.

7. (*a*) When are mica plugs usually used and why? (*b*) What disadvantages has the mica plug?

8. (*a*) What advantages are claimed for the closed-end spark plug? (*b*) What are its disadvantages?

9. Explain how the shape and composition of electrodes affect spark plug performance.

10. In case spark plugs of the type shown in Fig. 114 were used with a battery ignition system, what should be the polarity of the two electrodes to give best performance? Why?

11. What are the advantages of multiple-pointed plugs?

12. Explain the special features of the "Radd" spark plug.

13. What is the principle of the spark intensifier?

14. Explain how to test spark plugs for electrical and gas leakage.

SECTION VI

TYPICAL BATTERY IGNITION SYSTEMS

1. Name the component parts of a typical battery ignition system explaining the function of each.

2. (*a*) Which type of breaker requires the fastest ignition coil, and why? (*b*) Of the two breakers shown in Fig. 126 which is best suited for high speed service? Why?

3. (*a*) What is the purpose of the distributor? (*b*) Explain the difference between the gap and contact types of distributor heads.

4. What is the function of the ignition resistance unit?

5. Explain the function of the Automatic spark advance mechanism as used in many battery ignition systems.

6. (*a*) What are the special features of the Atwater-Kent ignition breaker, type K-2? (*b*) What type of ignition coil should be used with it?

7. (*a*) Describe the principal differences between the type CC and RA Atwater-Kent ignition breakers. (*b*) Give the recommended contact opening adjustment of each.

8. (*a*) Explain the function of the Connecticut Automatic Kick-out Switch. (*b*) What are the principal differences in the type H and type K switches?

9. (*a*) Explain the advantages of the three-legged shaped core used in the Remy coil as shown in Figs. 89 and 150. (*b*) What is the purpose of the polarity changing type switch as shown in Fig. 151?

10. (*a*) In the North East ignition coil, shown in Fig. 153, what advantages are gained by the external wrapping of soft iron wire? (*b*) What means is provided for timing the North East Breaker with the engine?

11. What are the outstanding features of the Westinghouse type SC breaker?

12. What are the special features and advantages of the Bosch Model Tc-30 coil?

13. Describe the usual procedure in timing a battery ignition system to the engine.

SECTION VII

SPECIAL BATTERY IGNITION SYSTEMS

1 What is the object of the double breaker and double set of spark plugs used on the Pierce-Arrow engine?

2. What would be the effect upon ignition in case one breaker on the Pierce-Arrow opened earlier than the other? Why?

3. In the Delco ignition system on the Cadillac Eight, Fig. 184, what is the purpose of having the two breakers operating in parallel?

4. How would ignition be effected if one breaker opened earlier than the other?

5. (*a*) How does the distributor and breaker unit for the Lincoln Eight differ in principle and construction from that used on the Cadillac Eight? (*b*) Why is this difference necessary?

6. Enumerate the various electrical ignition troubles that might cause misfiring of all cylinders in the right block only, of the Packard "Twin six" the ignition diagram of which is shown in Fig 190.

7. Explain why battery ignition is more suitable on the Liberty "Twelve" aircraft engine than magneto ignition.

8. (*a*) What is the function of the Auxiliary breaker used in the Delco ignition system on the Liberty "Twelve" engine? (*b*) How is it timed with respect to the main breakers?

9. By means of a sketch explain how you would proceed to time the two breakers of the Pierce-Arrow Delco ignition unit to open at the same instant.

10. Explain how you would proceed to time the breakers of the Cadillac Eight to open at the same instant illustrating the method by means of a sketch.

11. Describe the general procedure used in checking the ignition timing on a Twelve-cylinder V-type engine.

SECTION VIII

LOW-TENSION MAGNETOS

1. Name the component parts of a typical low-tension magneto explaining the function of each.

2. (*a*) What precautions are necessary in placing magnets on a magneto? Why? (*b*) What should be the strength of magneto magnets to give satisfactory service?

3. (*a*) In an armature type magneto, in what position is the armature with respect to the pole pieces when the maximum voltage and current are produced? Why? (*b*) Referring to Fig. 205, what would be the effect on ignition if the breaker be timed to open at point *B* on full advance position?

4. Explain the principal differences between the armature-wound and inductor-type magnetos.

5. How should the magneto distributor be timed with respect to the time of breaker opening and armature position?

6. Explain the difference in principle between the low-tension magneto ignition system of the interrupted-primary type and the interrupted-shunt type.

7. In the Splitdorf low-tension magneto ignition system, Fig. 211, what would be the effect upon the operation of the system if the two wires connecting to terminals 2 and 3 on the coil box should be reversed?

8. Does the Remy Models P and 32 magneto system, Fig. 214, operate on the interrupted-primary or interrupted-shunt principle? Why?

9. Trace the path of the primary current in the Remy, Model RL, magneto ignition system, Fig. 217, with the switch (*a*) on battery position, and (*b*) on magneto position.

10. (*a*) Explain the purpose and principle of operation of the push-button as found on most low-tension magneto dual systems. (*b*) Why are the push-button contacts normally closed in some systems and normally open in others?

11. Explain briefly the principles of the Ford magneto.

12. Why is it not necessary to time this magneto with the engine?

SECTION IX

HIGH-TENSION MAGNETOS—ARMATURE TYPES

1. Explain briefly how the armature-type high-tension magneto differs from the low-tension type.

2. (*a*) What is the purpose of the ground brush? (*b*) What harm may result through operating the magneto without the ground brush making proper contact?

3. (*a*) How does the interrupter for the armature-type high-tension magneto differ from that used on the low-tension magneto? Why? (*b*) What is the normal contact opening?

4. Explain briefly how the high-tension current is produced in the high-tension magneto for producing ignition.

5. What is the location and function of the condenser in the armature-type high-tension magneto?

6. (*a*) Explain how the distributor should be timed with respect to the interrupter opening and armature position. (*b*) What markings are usually provided as an aid in distributor timing?

7. Explain how ignition is turned off when a high-tension magneto of the armature type is used.

8. (*a*) How is it possible for the Bosch NU4 magneto to provide ignition satisfactorily for a four-cylinder engine without the use of a distributor? (*b*) What precaution is necessary in timing this magneto to the engine?

9. (*a*) Explain how the Eisemann magneto, type G4-II Edition, differs from the type G4-I Edition. (*b*) Where is the safety gap on the Eisemann magneto and what is its function?

10. Explain the reason for the peculiar shape pole construction in the Simms magneto.

11. What are the outstanding features of the Kingston, Model 0, magneto?

12. (*a*) Explain the advantages you see in the Mea magneto over the usual armature-type high-tension magneto. (*b*) How is it possible to obtain such a large spark advance range with this magneto?

SECTION X

TYPICAL HIGH-TENSION MAGNETOS—INDUCTOR TYPES

1. Explain the difference between the revolving-inductor type and the revolving-pole type high-tension magneto.

2. (*a*) Is the K-W magneto of the revolving-inductor or the revolving-pole type? Why? (*b*) How many current impulses are obtained per revolution in this magneto? (*c*) What advantages are thereby obtained?

3. Explain how the polarity of a high-tension spark may be determined.

4. Describe briefly the principles of operation of the Dixie magneto.

5. What is the internal timing of the Dixie magneto with respect to distributor position, rotor position and time of breaker contact opening on advance and retard positions?

6. (*a*) How does the Splitdorf "Aero" magneto differ from the Dixie model? (*b*) What advantages are claimed for the "Aero" magneto?

7. Are the successive high-tension ignition sparks produced by the Teagle magneto (Figs. 278 and 280) of like polarity or do they alternate? Why?

8. How do the magnets of the Teagle, Model 77, Magneto differ from the usual construction?

9. What are the outstanding features of the Scintilla magneto, type AG4?

10. Describe the usual procedure followed in timing a high-tension magneto of the four-cylinder type to the engine.

SECTION XI

SPECIAL IGNITION EQUIPMENT

1. What is the purpose of the Oscillating-type magneto?

2. Explain the principle of operation of the Webster Tri-polar Oscillator magneto.

3. Why is accurate internal timing particularly important in this magneto?

4. How does the Sumpter Plug-Oscillator current-wave characteristics differ from that of the Webster?

5. What is the principle of the Bosch Oscillator Magneto shown in Fig. 294?

6. What are the various methods used to improve magneto ignition during cranking?

7. Explain briefly the principle of the Simms magneto system used on 1915 and 1916 models of the Maxwell.

8. What ignition trouble in this system would prevent the engine starting if cranked with the electric starter but yet would permit the engine to start readily if cranked by hand?

9. Explain the operating principle of the Bosch high-tension magneto with auxiliary vibrator.

10. How does the Dual type high-tension magneto differ in construction from the ordinary type?

11. How could a high-tension dual-type magneto, such as the Bosch or Eisemann, be changed to provide ignition to the engine in case the coil and switch unit should be removed or become defective?

12. Explain the function of the impulse starter

13. In the Remy Motor cycle type battery ignition system, Fig. 312, what would be the effect upon engine operation if the No. 2 cam lobe were timed with the rear or No. 1 Cylinder? Why?

14. Explain the object in cutting away portions of the armature core and pole pieces as found in magnetos designed for V-type motorcycles.

15. What are the outstanding features of the Simms aviation magneto, Type L-8?

SECTION XII

IGNITION EQUIPMENT TROUBLES AND ADJUSTMENTS

1. Explain how a misfiring cylinder may be located with the engine running.

2. (*a*) What are the causes of carbonized or fouled spark plugs? (*b*) Explain what care should be taken in cleaning spark plug porcelains.

3. Explain how high-tension wiring may be tested for defective insulation.

4. (*a*) What effect would leaky insulation at the insulated breaker terminal of a battery ignition breaker have upon ignition? Why? (*b*) How can it be tested for leakage?

5. (*a*) What will be the effect upon ignition if the interrupter contacts of the Atwater-Kent open-circuit type breaker, type K-2, are set at too wide an opening? (*b*) If set too close?

6. (*a*) Enumerate the troubles most common to closed-circuit type breakers. (*b*) How may the breaker spring tension be determined and adjusted?

7. Explain how a condenser may be tested for the following: (*a*) Leakage, (*b*) Short circuit and (*c*) Open circuit.

8. What are the likely causes for excessive sparking and rapid pitting of the beaker points in a battery ignition system?

9. What are the indications when ignition is timed too early? When timed too late?

10. Explain how you would proceed to time a battery ignition system to the engine in which the cam is adjustable on the shaft.

11. Explain briefly how to test a high-tension magneto on either the bench or the engine for the production of suitable ignition sparks.

12. (*a*) Name at least ten causes any of which might prevent a high-tension armature-type magneto from providing proper ignition in the engine.

13. How would you proceed to test the condenser in a Bosch high-tension magneto armature?

14. (*a*) Describe the procedure in recharging magneto magnets, explaining the precautions that must be taken. (*b*) What should be the strength in pounds pull of the usual high-tension magneto magnet of the Bosch or Eisemann type, and how may its strength be determined?

16. What methods are used in charging the magnets of the Ford magneto, and what are the advantages and disadvantages of each?

SECTION XIII

STORAGE BATTERY CONSTRUCTION AND OPERATION

1. Name the component parts of the starting and lighting type storage battery, explaining the function of each.

2. (*a*) Of what materials are the plates and grids composed? (*b*) What advantages, if any, do you see in the "diamond grid" construction? What disadvantages?

3. (*a*) Explain the important points that should be considered in selecting best quality wood separators. (*b*) What woods are generally used for separators and why?

4. What are the special features of the Willard Separator?

5. What is the composition of the battery solution and what should be its strength in a fully charged cell?

6. Explain briefly the action of the lead-acid cell on discharge.

7. What is its action on charge?

8. What is meant by "sulphation" and how can it be prevented?

9. Explain how the density of the electrolyte and the cell voltage vary with the condition of charge.

10. What determines the capacity of a storage cell and how may it be determined?

11. What factors control the discharge rate of a battery?

12. What is meant by internal resistance of a storage battery and what effect does it have on battery performance?

13. How may the internal resistance of a 6-volt automobile type storage battery be determined?

14. How is the efficiency of a storage battery determined?

SECTION XIV

STORAGE BATTERY CHARGING AND TESTING

1. (*a*) Explain the hydrometer method of determining the condition of charge of a storage battery. (*b*) What readings indicate the condition of: *three-fourths* charge, *one-half* charge, *one-fourth* charge, and *complete* discharge, respectively?

2. What conditions might cause the specific gravity in one cell to fall considerably below that of the other cells in the battery?

3. What is the rule for making temperature corrections in testing storage batteries at different temperatures?

4. How may the polarity of charging lines be determined?

5. Calculate the voltage required to charge 8 6-volt and 2 12-volt batteries connected in series.

6. How may the *start* and *finish* charging rates of an automobile storage battery be determined in case they are not known?

7. Explain how one can determine when a battery has reached its full state of charge.

8. What is meant by *balancing cells* and how is it accomplished?

9. (*a*) What precautions must be taken in mixing electrolyte? (*b*) What is the specific gravity of chemically pure sulphuric acid?

10. Explain the methods used in charging batteries in wet storage.

11. Calculate the cost of power required to charge 10 6-volt batteries connected in series on a 110 volt D.C. circuit at an average current of 7 amp. for a period of 18 hr. at $.12 per kilowatt hour.

12. Of what value is the cadmium test in testing storage batteries? How is it made?

SECTION XV

BATTERY CHARGING EQUIPMENT

1. By means of a sketch explain the connections and number of 110-volt 50 watt lamps that would be necessary to charge a 6-volt battery on a 220-volt D.C. circuit at a charging rate of 6 amps., the lamps being used for resistance.

2. How may a 6-volt automobile battery be charged from a 32-volt farm-lighting plant which uses a 16-cell battery?

3. Why is it necessary to use a rectifier when alternating current only is available for charging?

4. Explain the principle of the electrolytic single-cell-type rectifier.

5. What is the principle of the King mechanical rectifier?

6. (*a*) Is the Westinghouse vibrating rectifier of the half-wave or the full-wave type? Why? (*b*) What disadvantages do you see in this type rectifier?

7. Explain the principle of the Mercury Arc rectifier.

8. Explain the principle of the Tungar rectifier.

9. Explain the principles of Constant Potential charging.

10. What advantages are claimed for the Constant Potential method of battery charging?

11. What are its disadvantages, if any?

SECTION XVI

BATTERY TROUBLES AND REMEDIES

1. Enumerate the various indications and causes of a battery becoming discharged or weak while in automobile service.

2. Name ten conditions which will prevent a battery from holding a charge.

3. What is meant by abnormal or over-sulphation?

4. What effect has under-filling on battery performance and life?

5. What treatment would you give a battery that is found to be over-sulphated in order to restore it to a healthy fully-charged condition?

6. How is it possible for one cell of a battery to become reversed in polarity?

7. What is meant by "over-charging" and what effect does it have on the battery?

8. What procedure is recommended to remedy a battery in which the plates are badly buckled and discharged?

9. (*a*) What is the cause of battery plates becoming granular or disintegrated? (*b*) What harmful effect may result from "sediment?"

10. (*a*) To what causes may be attributed separator failure? (*b*) What are the indications of defective battery insulation?

11. (*a*) What effect has impurities, such as iron, if introduced into the electrolyte of a battery? (*b*) What is the effect upon the battery when an electrolyte of sulphuric acid and water stronger than 1,300 sp. gr. is used?

12. How may the corrosion that is often found on the battery terminals be removed and prevented?

13. (*a*) What effect has freezing on a battery? (*b*) How may freezing be prevented?

14. Explain how you would test a battery jar for cracks?

15. Describe briefly the procedure in taking a typical starting and lighting type battery apart for inspection and repairs.

16. What precaution should be taken before bringing an open flame near a battery that has been charging? Why?

SECTION XVII

LIGHTING EQUIPMENT AND WIRING

1. Name the component parts of a typical automobile lighting system explaining the function of each.

2. What means are provided for aligning headlights?

3. Explain the difference between focusing and non-focusing types of bulbs. Where is each type used?

4. (*a*) What markings should be found on all bulbs? (*b*) What size bulbs are usually used for headlights?

5. Explain the difference between the single-wire grounded and the two-wire type of lighting system. Which is the more commonly used and why?

6. Enumerate the various methods used in headlight dimming, explaining the principle of each.

7. Draw a circuit diagram of a headlighting system wired on the series-parallel plan, indicating the path of current on "bright" and "dim" positions by means of single and double headed arrows, respectively.

8. What precautions should be taken in soldering rubber insulated wires?

9. Explain the principle of operation of the Delco protective circuit breaker.

10. (*a*) What is the purpose of the "stop" light and how is it usually connected and operated. (*b*) What size bulb is generally used in the stop light?

SECTION XVIII

ELEMENTS OF HEADLIGHT ILLUMINATION

1. Explain the difference between primary and secondary light.

2. Give definitions of the following terms. (*a*) candle, (*b*) candlepower, (*c*) mean spherical candlepower and (*d*) the foot-candle.

3. (*a*) What are the factors governing the intensity of illumination on a surface? (*b*) What factors govern the brightness of an object?

4. Explain how the intensity of illumination on a plane varies as the distance.

5. Explain the four causes of light interference, namely, absorption, refraction, reflection and diffusion.

6. What is the principle of the headlight reflector?

7. Explain the effect of bulb filament position on the reflected light rays with the filament in the following positions: (*a*) at focal center, (*b*) behind focal point and (*c*) ahead of the focal point.

8. Describe the following means of adjustment used in headlight focusing: (*a*) inside, (*b*) outside, (*c*) bulb and (*d*) rim.

9. What bulb positions are understood when referred to as being in No. 1, No. 2, No. 3, and No. 4 adjustment, respectively?

10. What is meant by headlight glare and what causes it?

11. What minimum road illumination values are generally considered proper for safe driving?

12. Explain the principle of operation of the foot-candle meter.

13. Describe the general procedure followed in adjusting a pair of headlamps that are out of alignment.

14. Enumerate the various methods employed in preventing headlight glare explaining the principle of each.
15. Explain how to properly clean and polish tarnished reflectors.

SECTION XIX

ELEMENTS OF STARTING AND GENERATING EQUIPMENT

1. Name the component parts of a typical electric starting and generating system, explaining the function of each.
2. Referring to Fig. 476, explain briefly how the operation of the water system corresponds to the automobile electrical system.
3. What methods are used in mounting and driving generators?
4. What is the usual speed of the generator with respect to the engine speed?
5. What is the function of the universal drive coupling used with some generators?
6. Describe briefly the following types of starting motor drives: (*a*) sliding pinion, (*b*) magnetic and (*c*) Bendix.
7. Explain the operation of the Bendix drive.
8. What advantages are claimed for it?
9. Explain the principle of the over-running clutch.
10. What is the function of the noisy-type over-running clutch used in some Delco generators?

SECTION XX

THE GENERATOR AND THE REVERSE CURRENT CUT-OUT

1. Give definitions of the following: (*a*) dynamo, (*b*) generator, (*c*) motor, and (*d*) starter-generator.
2. Name the component parts of a typical automobile generator explaining the function of each.
3. Explain the difference between a shunt-wound and a series-wound dynamo.
4. Explain step by step how a voltage builds up in a shunt-wound generator.
5. (*a*) How may the residual magnetism of a generator be tested for polarity? (*b*) How can a generator field frame be given residual magnetism in case it should become weak or reversed?
6. Name ten causes which will prevent an automobile generator from building up a voltage.
7. Explain the difference between differential compound wound generators having long-shunt and short-shunt field connections, illustrating same by sketches.
8. What is the purpose of the series field winding when used in automobile generators?

9. What is the function of the reverse-current cutout?

10. Explain the operation of the cutout (*a*) when closing and (*b*) when opening the circuit.

11. Explain how a 6-volt cut out may be adjusted to "cut-in" and "cut-out" at the proper time.

12. How would the method of cutout adjustment differ in case it is used with a 12-volt type generator?

SECTION XXI

ARMATURE CONSTRUCTION AND OPERATION

1. Describe briefly the construction of the automobile type armature.

2. Why is it necessary to laminate the armature core?

3. (*a*) Explain the difference between *coil pitch* and *pole pitch.* (*b*) What is meant by *front pitch* and *back pitch?*

4. By means of sketches explain the difference between progressive and retrogressive types of armature windings.

5. (*a*) Explain what is meant by a lap-wound four-pole armature. (*b*) What advantages has this type of winding?

6. Explain how a wave-wound armature differs from the lap-wound type, illustrating same by a sketch showing at least one complete coil on the armature core.

7. Explain how it is possible to use only two brushes on a four-pole wave-wound armature.

8. What advantages has the wave-wound type armature over the lap-wound type?

9. (*a*) Explain the causes of magnetic field distortion with generator running under load. (*b*) What effect has the armature field distortion upon generator brush position?

10. (*a*) What causes the field distortion in a motor armature? (*b*) What is the direction of this distortion with respect to armature rotation?

11. What is meant by Eddy currents and what causes them?

12. Explain why a generator armature will over-heat quickly that has been allowed to rub on the pole-pieces, assuming that the electrical load on the armature is not excessive and that the armature windings are not defective.

SECTION XXII

METHODS OF GENERATOR REGULATION

1. Name the various methods used in regulating the output of the automobile generator, explaining briefly the principle of each.

2. By use of a sketch explain the principle of reverse-series generator regulation.

3. Can a car equipped with a generator of this type be driven with the storage battery removed without endangering the electrical system? Why?

4. What special characteristics has the Westinghouse generator, Figs. 532 and 533, when the lights are turned on?

5. By means of a sketch, explain the principle of operation of a vibrating type regulator which will control the current output of a generator.

6. Explain how the principle of operation of the voltage type regulator differs from the current type referred to in question 5.

7. (*a*) What advantages are claimed for constant-voltage generator regulation? (*b*) What disadvantages does it have?

8. Draw a sketch showing the circuits of a simple generator and lighting system in which the generator is regulated by a vibrating type relay which provides both current and voltage regulation, and explain its principle of operation.

9. How may the charging rate of a generator equipped with a voltage regulator be increased or decreased? Why?

10. By means of a sketch explain the principle of third-brush regulation

11. How may the charging rate of a third-brush type generator be increased or decreased, giving reasons for your answer?

12. (*a*) Explain how the charging rate of a third-brush type generator varies as the speed increases. (*b*) What advantages do you see in this method of regulation?

13. What is the function of the thermostat in the Remy generator?

14. (*a*) What action of the dash ammeter would indicate that the resistance unit of a Remy thermostat is burned out? (*b*) What scheme would you devise in adjusting the thermostat to open at a definite temperature, say 175 deg. F.?

SECTION XXIII

STARTING MOTORS AND STARTER-GENERATORS

1. What starting motor gear ratios are usually obtained when a single-reduction type Bendix drive is used?

2. What advantages and disadvantages do you see in the double-reduction type starting motor such as shown in Fig. 556 *B*?

3. What conditions will cause a starting motor to run in the wrong direction from that desired?

4. Explain briefly the operation of the North East starter-generator, Model G.

5. What factors govern the cranking power required of a starting motor?

6. How would you test a starting motor to obtain its maximum lock-torque and current consumption?

7. In case the current draw and lock-torque of a starting motor should test below normal, what might the trouble be due to?

8. What effect will poor brush contact have on starter performance? Why?

9. What should the brush spring tension be on the average starting motor?

10. How can the brush tension be measured?

SECTION XXIV

BRUSHES AND BRUSH RIGGING

1. Explain the function of the various types of dynamo brushes explaining the material usually used in each type.

2. Why does the material used in the generator brush differ from that used in the starting motor?

3. What is meant by an abrasive type brush and why is it necessary?

4. (a) What causes sparking of the generator brush when mounted in the wrong position on the commutator? (b) How is the sparking reduced to a minimum?

5. What important characteristics must a brush have that is to be used in a starter-generator, and why?

6. Give definitions for the following terms: *specific resistance; contact resistance; current density;* and *coefficient of friction.*

7. (a) Explain briefly the difference between brush hardness, abrasiveness and brush density. (b) What is the difference between real density of brushes and the apparent density?

8. How may the specific resistance, or resistance per inch cube, of a generator brush be determined?

9. What should be the normal brush spring tension in the usual generator and starting-motor and how may it be measured?

10. (a) Explain the procedure in "sanding-in" generator brushes to fit the commutator. (b) How would you proceed to sand-in the brushes where the brush rigging is entirely enclosed; such as, in the Westinghouse generator, Model 400, shown in Fig. 544?

SECTION XXV

TYPICAL STARTING AND LIGHTING SYSTEMS—TWO UNIT TYPES

1. (a) What method of regulation is used in the Auto-Lite generator used on the Chevrolet 490, as shown in Fig. 548? (b) How would you proceed to operate this car with the storage battery removed without endangering the electrical system?

2. (a) In the Bijur system used on the Packard Twin-Six, Fig. 583, what is the object of reversing the regulator disconnecting plug every 500 to 1,000 miles of travel? (b) What method of regulation is used and how may the generator be adjusted to a higher or lower charging rate?

3. (a) In the Bosch starting and lighting system used on the Essex, how may the charging rate be increased or decreased? (b) What will be necessary to operate this car with the storage battery removed?

4. (a) In the Delco starting and lighting system for the Nash six, shown in Fig. 586, how is it possible for the system to operate without a reverse current cutout? (b) What effect would a loose fan belt have upon the generator performance?

5. Referring to Fig. 588, which shows the circuit diagram of the Delco system on the Oldsmobile, Model 30, it will be noted that no cutout relay is used. In case the driver of this car should coast down a long grade with the ignition cut off, using the engine as a break (as is often done in mountain travel) what danger might happen to the generator windings and why?

6. (*a*) How does the starting motor on the Packard "Straight Eight" differ from the usual starting-motor construction? (*b*) Why should care be taken not to lift the third brush of the Packard generator with the engine running? (In most systems this would merely prevent the generator from charging.)

7. (*a*) In the Ford electrical system, Fig. 591, what might result in case the two lower junction block terminals (those connecting to the magneto plug and the generator wire, respectively) should become accidently short-circuited, and why? (*b*) Why would reversing the connection of the right head-light plug cause this light to burn dim when the other one burns bright and vice versa? (*c*) What should be done in case the car is to be operated off the magneto with the battery disconnected and why?

8. (*a*) In the Gray & Davis system shown for the Paige, Fig. 593, what effect has the connecting of the lighting wire to the middle of the regulator current coil have upon the generator output and why? (*b*) How would you increase or decrease the charging rate of this type generator?

9. (*a*) How does the North East starting-motor as used on the Reo differ in its method of cranking from the usual starting-motor drive construction? (*b*) What would be the effect on the generator in case the ground wire on the cutout would be removed, and why?

10. (*a*) Explain the special characteristics of the Remy generator as used on the Oakland, Model 6-44, Fig. 598. (*b*) In case the cutout cover cannot be removed, how may it be determined whether or not this unit is operating in case the ammeter does not show charge at normal driving speeds?

11. (*a*) How does the generator on the Studebaker, Fig. 600, differ in general construction and mounting from the usual practice? (*b*) How are the headlights dimmed in this system?

12. (*a*) What type of armature, lap-wound or wave-wound, must be used in the Westinghouse generator, Fig. 603, which is a four-pole generator using two main brushes? Why? (*b*) Where is the cutout located used with this generator?

SECTION XXVI

TYPICAL STARTING AND LIGHTING SYSTEMS—SINGLE UNIT TYPES

1. What is the object of the three terminals on the starting switch as found in the Allis-Chalmers starting and lighting system, on the Grant six, Fig. 606?

2. What method of generator regulation is used in this system and how may the charging rate be increased or decreased?

3. Explain briefly the operating principle of the Delco single-unit system as used on the Buick six, Fig. 608.

4. What would you say would be the effect upon the ignition system in case the induction coil was mounted in the reversed position; *i.e.*, with the wiring of the two primary terminals reversed?

5. What precaution is necessary to operate this system without a storage battery, using dry cells to supply ignition current?

6. In the Delco system on the Cadillac eight, Fig. 612, what prevents the generator from generating during the cranking process?

7. What is the function of the vibrating and locking circuit breakers, and how do they operate?

8. On the North East starter-generator, Model D, Fig. 616, it will be noticed that there is an electrical connection between the two resistance units to the base of the limiting relay. What is the purpose of this connection and what would you say would be the cause of one resistance unit operating hotter than the other with the generator in operation?

9. What is the purpose of the condenser shown between the two lower poles?

10. Explain how the starter chain for the North East starter generator on the Dodge, should be adjusted for the best operation.

11. In the Simms Huff starting and lighting system, as used on the Maxwell, Fig. 619, what voltage is supplied to the lighting system during the cranking operation and why?

12. What methods of regulation are used in this system and how may the charging rate be adjusted?

13. What conditions would cause one-half of the battery used in this system to become discharged while the other half does not?

SECTION XXVII

ELECTRICAL ACCESSORIES

1. Explain the various schemes used in operating horns for automobile purposes.

2. How may the tone of the motor-driven horn be adjusted, such as the Sparton, Fig. 622?

3. (*a*) Explain the principles of the Ford alternating current type horn. (*b*) How may its tone be adjusted?

4. (*a*) What is the purpose of the resistance unit found on the Delco vibrating type horn, Fig. 625? (*b*) How may the tone of a vibrating type horn be adjusted?

5. Show a wiring diagram giving the method of connecting an electric windshield wiper to the electrical system.

6. What effect does wiper pressure have on current consumption of the unit and why?

7. What care should be taken in adjusting the pressure of the rubber wiper?

8. Does the unit require more current when the glass is dry or wet, and why? (*b*) What should be the maximum current consumption?

SECTION XXVIII

AUTOMOTIVE ELECTRICAL TESTING INSTRUMENTS

1. (*a*) Explain briefly the operation of the Solenoid meter shown in Fig. 630. (*b*) Will this meter register direct current or alternating current or both and why?

2. What causes the deflection of the needle in the magnetic vane type ammeter shown in Fig. 631?

3. What effect would a weakened magnet have upon the readings of the instrument?

4. How does the Westinghouse ammeter, type BT, differ from the usual construction?

5. What is meant by a C.O.D. indicator and where is it generally used?

6. What causes the needle deflection in the D'Arsonval moving-coil-type meter, Fig. 636?

7. In case of a weak magnet, would this meter register too high or too low and why?

8. Explain the working principle of the shunt when used with a millivoltmeter in measuring electrical current.

9. How is it possible to use the same meter and moving coil construction in measuring different voltages?

10. What are the special advantages found in the Hoyt rotary type meter for automotive electrical testing?

11. What advantages do you see in the Jewell meter, Fig. 645, for automotive electrical testing?

12. (*a*) How would you proceed to use a high grade electrical tesing meter in checking the accuracy of the dash ammeter as used on the car? (*b*) What causes the ammeter readings to be different when the current is measured close to the generator and when measured at some other point on the car, such as near the instrument board or battery?

SECTION XXIX

ARMATURE AND FIELD TESTING

1. What is meant by motorizing the generator and in what way can this operation be used in diagnosing generator troubles?

2. (*a*) Explain what is meant by an open-circuited armature coil stating its effect upon generator operation. (*b*) What are the usual causes of this trouble and what are the usual indications?

3. What is meant by a short-circuited armature coil and what are its causes and indications?

4. (*a*) What is meant by a grounded armature coil? (*b*) Explain how an armature may be tested for grounded winding.

5. Explain the effect the following troubles have upon generator operation: (*a*) worn bearings; (*b*) commutator out of round; and (*c*) bent armature shaft.

6. Explain how you would test an armature for short-circuited armature coils using a growler in testing.

7. Explain how an armature with an open-circuited coil might be tested on a growler.

8. Explain how you would test for a short-circuited armature coil using a low-reading voltmeter.

9. How would you test for an open-circuited coil using a low-reading voltmeter?

10 In rewinding armatures it sometimes happens that the winder will reverse the leads connecting to adjacent commutator bars. How may this mistake be discovered using a low-reading voltmeter?

11. What are the troubles that may occur in the field winding of a generator, explaining the effect of each upon the operation of the generator?

12. Explain how you would locate an open-circuited field coil in case a 6-volt storage battery and 6-volt test lamp were the only equipment available for testing. Explain same by means of a sketch.

SECTION XXX

GENERATOR AND STARTING-MOTOR TROUBLES AND REMEDIES

1. What conditions may prevent a generator from charging with the engine running at normal charging speeds?

2. In case the cutout is suspected as not closing properly, how may this be quickly determined without removing the cutout cover?

3. What effect has high mica on generator operation and what is the proper way of eliminating this trouble?

4. (*a*) How often should a generator of the ball bearing type be lubricated? (*b*) What is the effect of over-lubrication?

5. How would you go about it to reverse the direction of rotation of a shunt-wound generator which uses a voltage regulator for controlling the generator output?

6. Explain briefly the procedure in adjusting and checking the operation of the 6-volt cutout.

7. What harm would result from installing a battery in a car with the polarity reversed and why?

8. (*a*) In case a battery is installed with reversed polarity what must be done to make the ammeter read properly? (*b*) Will the generator reverse itself automatically? If so, why?

9. Explain briefly how the charging rate of a generator may be increased with the following methods of regulation: (*a*) With governor regulation. (*b*) Differential field winding. (*c*) Vibrating type regulator. (*d*) Third brush regulation.

10. What is the usual procedure that must be followed in case it is desired to operate an automobile with the storage battery removed without endangering the electrical system?

11. What would you say might be the trouble if the lights dim down when the starting switch is fully compressed but with the starting-motor showing no signs of life?

12. (*a*) What might be the trouble if the starting-motor spins but does not crank the engine? (*b*) What would cause the starting-motor to keep on running after the starting switch is released?

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